F. J. HODGES · I. LAMPE · J. F. HOLT

RADIOLOGY for Medical Students

DIAGNOSIS · THERAPY

THIRD EDITION

RADIOLOGY
for Medical Students

RADIOLOGY

for Medical Students

FRED JENNER HODGES, M.D.
PROFESSOR AND CHAIRMAN, DEPARTMENT OF RADIOLOGY,
UNIVERSITY OF MICHIGAN

ISADORE LAMPE, M.D.
PROFESSOR, DEPARTMENT OF RADIOLOGY,
UNIVERSITY OF MICHIGAN

JOHN FLOYD HOLT, M.D.
PROFESSOR, DEPARTMENT OF RADIOLOGY,
UNIVERSITY OF MICHIGAN

THIRD EDITION

THE YEAR BOOK PUBLISHERS • INC.

200 EAST ILLINOIS STREET • CHICAGO

Reprinted, July, 1948

Reprinted, January, 1951

Second Edition, August, 1954

Reprinted, July, 1956

Third Edition, September, 1958

PRINTED IN U.S.A.

Preface to Third Edition

DURING THE past decade some 1,500 Michigan juniors have proved to its authors that *Radiology for Medical Students* represents a thoroughly practicable means of presenting the fundamentals of clinical radiology. Use of this volume has made it possible to dispense with formal lectures, thereby increasing the opportunity for informal teaching by means of the case method.

Once again, on the occasion of preparing a new edition, the urge to expand all sections has been suppressed, preserving the original aim of presenting no more material than that which can be considered necessary to sound undergraduate teaching. Revision has been extensive in order that rapidly changing concepts might be presented in proper perspective. To make room for new material the description of x-ray record keeping and diagnostic cataloguing has been deleted.

In the field of pediatric radiology, infantile cortical hyperostosis, infantile skeletal trauma and hypervitaminosis have been accorded proper attention. The radiologic features of osteomyelitis, syphilis, rickets and scurvy have been reappraised in the light of their great historical importance. Sialography and presacral CO_2 injection have been discussed briefly, as well as the currently promising methods of studying the act of micturition in children. Public concern over the biologic hazards of exposure to radiations of all sorts has led to expansion of material bearing on this subject.

A chapter dealing specifically with the rapidly expanding subject of cardiovascular radiology has been added. The revised text of the section on therapeutic radiology reflects the declining use of radiation methods in the treatment of nonmalignant lesions. New material has been added concerning the employment of $cobalt^{60}$ as a source of high-energy gamma radiation.

It is hoped that edition three will serve medical students and their teachers as well as, if not better than, its predecessors. The authors wish to acknowledge with gratitude the helpful assistance provided by Mr. Gerald Hodge and Mr. Roland Burd in the preparation of new illustrative material. Permission graciously granted by our colleague Dr. Melvin Figley and Mr. Charles Thomas to use illustrative material is deeply appreciated.

The Authors.

June, 1958
Department of Radiology
University Hospital
University of Michigan

Preface to First Edition

THIS BOOK is aimed at, written expressly for, dedicated to the undergraduate student of medicine. It is hoped that he will find it to be an easily readable, plausible and convincing exposition of the medical uses of x-rays, and radium. We who have assumed the responsibility of adding still another volume to the student's bookshelf have adhered steadfastly to a mutual promise that nothing shall be included that is unnecessary to the clear and usable understanding of radiology which every physician should possess. On the other hand we have not begrudged whatever

space seemed necessary to expound fully the rationale of the diagnostic and therapeutic branches of the subject because we hope to induce medical students to appreciate how intimately radiology permeates medicine in all of its branches.

If every medical student were to attempt exhaustive investigation and mastery of every phase of modern medical knowledge, the task would be, of course, impossible of accomplishment. It seems to us that overambitious planning of the courses of instruction offered by individual departments has serious drawbacks. Students acquire neither the skills and detailed knowledge expected by their teachers nor the well-rounded basic understanding which all physicians need. In the case of radiology we aspire to supply students with the means whereby this second goal may be reached. We are well content to rely on established methods of postgraduate study for the training of those few medical students who may choose to become radiologists later in their careers. For those physicians required by clinical activities to acquire particularized information concerning the utilization of radiologic methods, many atlases and monographs are already available.

Only the essential matters relating to the apparatus peculiar to radiology are presented since the reader is presumed to be interested in what radiology can do to be helpful in the practice of medicine rather than in implementation of technical accomplishments. It should be reassuring to him to learn that the technical operation of apparatus used in radiology can be mastered quite readily by persons with far less preliminary training than that required for admission to medical schools.

Diagnostic roentgenology and radiation therapy are presented as highly individualistic parts of a single medical specialty. A certain amount of information about radiation physics is necessary to a clear understanding of either branch of the subject, both of which make use of similar electrical equipment. Radiation therapy is a system of treatment based on the biologic action of various radiations. The tissue changes which x-rays can and do produce must be understood and respected by diagnostician and therapist alike if injury to patients and examiners is to be avoided. The introductory chapters to Part I and Part II

contain important background material permitting the specific subdivisions which follow to be treated with greater brevity and with less repetition than would otherwise be necessary.

Roentgenograms, diagrams, drawings and tables of classification are reproduced to clarify basic principles rather than to provide encyclopedic information. The practical limitations as well as the truly great potentialities of radiology are presented and discussed. The reading lists consist of carefully selected titles to guide students who may wish to delve more deeply into particular subjects. There has been no attempt to lean on collateral reading for the presentation of fundamentally important material.

It remains to be determined whether the recipe which has been followed will result in a dish which can be considered nutritious and at the same time will be found to be palatable by students. Reviewing the behavior and performance of fifteen classes of students at the University of Michigan who have seemed to thrive on similar fare, we have been encouraged to believe that it will.

The great assistance rendered by Mr. C. R. Burd in preparing the photographic reproductions of illustrative case material and that of Dr. Guillermo Santin and Dr. Fred J. Hodges III in making the drawings is acknowledged by the authors with sincere thanks.

THE AUTHORS.

Department of Radiology
University Hospital
University of Michigan

Table of Contents

1

Introduction

THE STORY behind the medical specialty of radiology—its origin, early development and rapid growth to maturity—reflects the tempo at which medical knowledge has been expanding since the Renaissance and is prophetic of the ever-increasing rate of growth which may be expected to continue in the centuries that lie ahead. Already medical historians are unanimous in listing the discovery of x-rays among the milestones that punctuate the onward march of medical science.

Against a background of medical lore and belief, warped by mysticism and by religious and philosophic dogma, there was initiated during the seventeenth century a continuous procession of brilliant medical advances. Five outstanding contributions, spaced over two centuries, represent the beginnings of physical diagnosis as we know it today. Harvey (1628) established the conception of the circulation of the blood; van Leeuwenhoek (1670) introduced microscopy; Auenbrugger (1761) fathered percussion: Laënnec (1819) put the stethoscope into the physician's hands, and in 1851 Helmholtz produced the ophthalmoscope. Slowly the clinical study of disease had been inaugurated and its implementation was begun.

Somewhat overlapping these developments in point of time, John Hunter, at the peak of his career in 1775, brought the surgeons, whose skills he had mastered and multiplied, into the sedate profession of medicine as an integral and honorable

component. In 1796 his student, Edward Jenner, presented the world with vaccination, the discovery that brought the age-old scourge of smallpox under control. Before the middle of the nineteenth century, Wells, Morton and Simpson proved the efficacy and practicability of inhalation anesthesia by means of nitrous oxide, ether and chloroform and opened for the practice of surgery vast new opportunities shortly to be expanded further by Lister's teachings regarding antisepsis. In 1865 Claude Bernard greatly stimulated the development of medical science with his classic treatise on the study of experimental medicine. Pasteur and Koch, through their extensive and variegated researches, provided an enormous impetus to medical thought by establishing the relationship of micro-organisms to many diseases.

In ever-quickening succession the world has accepted similar contributions to the advancement of medicine. At the beginning of the present century Gorgas and his brilliant group accomplished the first successes in combating yellow fever and malaria. In 1910 the monumental investigations of Ehrlich were crowned with the establishment of arsphenamine as an effective agent against syphilis. The work of Banting, Best and Macleod brought forth insulin in 1921 for the subjugation of diabetes. Minot and Murphy did the same for pernicious anemia in 1926 by recommending the feeding of liver to patients with this disease. The introduction of the sulfonamide drugs and the discovery of penicillin, just before World War II, revolutionized the management of many bacterial diseases, and to these two drugs much credit is due for the phenomenally low mortality rates among military casualties. During the postwar period, streptomycin, PAS and the series of drugs represented by isonicotinic acid have been widely used with striking success against tuberculosis. The antihistamines, though scarcely revolutionary, have been effective in the management of allergic problems. Cortisone and corticotropin, although perhaps not living up to advance notices, have been widely tested, with some spectacular results in the case of inscrutable diseases and some undesirable side effects which have been recognized and analyzed. Nobel prize-winning researches by Enders and Weller led to the development by Jonas Salk of an effective means of combating paralytic polio-

myelitis. Cardiac catheterization, its original conception and accomplishment earning Nobel prize recognition for Cournand and Richards, is closely related to the great advances which have come about in the diagnosis and surgical correction of many cardiovascular defects, both congenital and acquired. Truly the pace at which medical knowledge is advancing has quickened, and an even greater rate of acceleration is to be anticipated.

Wilhelm Conrad Röntgen's discovery of a new form of rays ranks with these, and innumerable additional contributions to the advance of medicine, as a new point of departure in medical thought. Like all of them, it has been followed by drastic alteration in the pattern of medical practice and has been associated with human benefits too far reaching to be easily appreciated. To understand fully and to evaluate the implications of radiology, one must look on medicine in its entirety—a torrent of scientific thought and accomplishment which continues to gain volume and momentum at a rate which staggers the imagination.

It is a matter of historical record that a German physics professor at the University of Würzburg made a momentous observation on the evening of November 8 in the year 1895. He found that there existed a hitherto unsuspected form of rays which possessed the strange and almost unbelievable property of penetrating objects and substances completely opaque to sunlight. Professor Röntgen's achievement was suitably acknowledged when he was awarded the first Nobel prize in physics in 1901. What a coincidence it was that physical science should have produced a discovery of such enormous magnitude to initiate the long list of Nobel prize awards which outline the brilliant history of modern physics! Although world-wide recognition properly belongs to Röntgen for his discovery, a large company of scientific observers and experimenters working independently over many generations had collected the necessary fragments of physical data and had developed the fundamental hypotheses which Röntgen pieced together in making his epochal observation.

Fortunately for medicine, Röntgen himself used living human tissues, among other test objects, to prove the penetrating property of the mysterious beam which he designated as x-rays. Had

he not tested his beam with living tissues, the attractive potentialities of x-rays in the field of medicine might well have gone unexplored for a considerable time. Actually the medical utility of the new form of energy was widely tested from the start. Popular fancy was at once attracted in this field; whereas the many practical uses in industry were developed rather slowly. Physicists throughout the world went to work quietly to strip the new rays of their mysteries, and the fruits of these labors have resulted in the development of an extensive and important field of physical experimentation and theory.

Our primary concern with x-rays is limited to their application in the practice of medicine. For a time the weak and inefficient apparatus required for their production was available only in progressive laboratories of physics and was accessible only under difficulties to physicians who wished to use it in their practices. Some few physicians interested in mechanical and electrical devices acquired the requisite equipment and began to explore the usefulness of the new rays in the examination of their patients. With such apparatus it was possible, in the months immediately following the discovery, to recognize bone fractures and metallic foreign bodies in the less bulky parts of the body. These otherwise hidden features could be observed in silhouette as dark shadows on the sickly green background of a glowing screen of fluorescent material held in the beam's path, or could be captured as permanent white images against the general blackening of a photographic plate. In the early dates, x-ray exploration of the thorax was an intriguing, though somewhat disappointing, experience.

Inquisitiveness of physicians is closely paralleled by their ingenuity. To a phenomenal degree x-rays have been used to amplify older methods of physical examination as well as to supersede them with unique diagnostic procedures entirely dependent on the x-ray principle. By leaps and bounds x-ray examination has permeated practically every subdivision of medical practice, providing physicians with factual information about their patients which today seems indispensable. The public mind has been quick to accept x-ray diagnosis at even more than its actual worth in comparison with other medical procedures.

The discoverers of fire and the wheel and the first manufacturers of glass and paper are lost in antiquity. Their priceless gifts to civilization have long since been appropriated as the common property of mankind—rugged essentials in our way of living. We feel that these tools of civilization came to us quite naturally and in due season as episodes in our ascent from barbarity; we are entirely unashamed to accept them as our just heritage from the distant past, as products of the race rather than the fruits of the ingenuity of individuals. We feel certain that sooner or later they would have been developed by man. So we may consider that x-rays were withheld as a locked secret, utterly useless until medicine in its ponderous development was prepared to use them to advantage.

In 1896, during further experimentation in the field which led to the discovery of x-rays, Henri Becquerel observed and proved the existence of a similar radiation which occurs spontaneously in the element uranium. Shortly thereafter, in 1898, Pierre and Marie Curie isolated the naturally radioactive element radium. Detailed experimentation and observation concerning these new radiations were slow and tedious, enormously stimulated, however, by the tremendous implications they provided in man's concept of the world in which he lives. A glittering panel of experimental physicists, theoretical physicists and philosophers have constructed from these initial truths regarding radiation an extremely useful, far-reaching and revolutionary understanding of the universe. In 1905 Albert Einstein conceived his breathtaking theory that mass and energy are interchangeable. Not until twenty-seven years had elapsed was it possible to subject his theory to actual proof. The equivalence of mass and energy is apparent only when energies imparted to particles accelerate them to speeds approaching that of light. The means of developing such energies were provided by the researches of Rutherford, Bohr, the Curie-Joliots, Compton, Lawrence and Livingston, Fermi and Oppenheimer, to mention but a few of those responsible for the discovery of artificially induced radioactivity and the development of the apparatus necessary to its practical accomplishment. The sanctity of the atomic nucleus, for centuries believed to be inviolate, has been effectively and thoroughly ran-

sacked, and its stupendous latent energies liberated. The far-reaching effects of the harnessing of nuclear energy for purposes of war in the political life of the world, currently so important a subject of debate among the diplomats of the world, stem from the same discoveries which provided medicine with x-rays for diagnosis and x-rays, radium rays and more recently discovered forms of radiation for therapeutic purposes. The tempo of investigation involving the multitudinous by-products of nuclear disintegration is extremely fast in every direction, but particularly so in all of the biologic sciences.

As compared with the rapid exploitation of x-rays in medical diagnosis, the utilization of radiant energy as a therapeutic agent lagged greatly. The tragic effects of the destructive biologic action of radiation that began to appear among the early workers required explanation, and this led to meticulous study of biologic effects paralleled by hasty and often ill-advised clinical trials for a great variety of lesions, visible and otherwise. Radiation therapy, which now occupies an honored and well-respected position in the treatment of many diseases, chiefly the malignant neoplasms, has come into its own through a dismal period of empiricism and inept fumbling. The establishment of an internationally accepted unit of radiation intensity, the roentgen, brought order out of chaos in 1925. Those radiations more recently made available for therapeutic use—beams of neutrons, electrons, protons and x-rays of fantastically great energy—must be subjected to exhaustive investigation and clinical trial. Fortunately the experimental work which must be completed before we can learn to use such radiations advantageously—in fact, before we can judge whether or not they possess valuable therapeutic properties—can be carried out in well-equipped laboratories by well-informed armies of investigators. The Manhattan Project, which delivered the frightful atomic bomb on schedule despite stupendous obstacles, served as an elaborate school for researchers in every phase of radiation. The hoped-for virtues of these newer agents, if they materialize, should become available to medicine with the speed and enlightenment we have the right to expect in our modern world and without the physical and mental anguish that attended the accumulation of comparable informa-

tion by the pioneers in radiation therapy. If the origin and development of radiology to its present level seem to have a miraculous flavor, we must prepare ourselves for an even greater impact on medicine when present intriguing leads in the field of nuclear physics begin to unfold.

Röntgen's discovery of x-rays occurred at a time when medicine was prepared to take full advantage of the benefits offered by penetrating light as an aid to the diagnosis of human ailments. The long period of blind empiricism which had effectually throttled progressive medical thought throughout the Middle Ages was followed in the seventeenth century by the development of logical conclusions based on experimentation. During the eighteenth century many of the steps had been taken which were needed to establish an enlightened approach to the understanding of medical problems. Throughout the nineteenth century the procedures of physical diagnosis were perfected and were widely and energetically practiced. The validity of antemortem observation was subjected to exhaustive testing at the autopsy table, and the ambition of physicians to acquire dependable information on which to plan medical and surgical treatment was widespread and deeply rooted. X-rays promised to carry "inspection" far beneath mere surface markings; threatened to challenge the supremacy of "percussion" and "auscultation" in determination of the density or compactness of underlying tissues.

The ambitious hopes of the early advocates of the use of x-rays in medicine seemed unlikely of realization. The shadows cast by skeletal parts deeply buried in soft tissues were at best poorly defined and were virtually unobtainable in large subjects. Medical problems related to metallic foreign bodies were too rare to provide the urge to complete exploitation of the newly found diagnostic agent. The feebleness of generating apparatus, the inefficiency of photographic materials and the fickleness of the early types of x-ray tubes led some prominent and influential physicians and surgeons to underrate greatly the potentialities of x-ray diagnosis. Some of these medical giants openly remarked and wrote that even in the case of broken bones, where detailed visual information would certainly be a boon to accurate reduction, the method could never be con-

sidered practicable because the services of a physicist and one or two attendants were needed to operate the apparatus and to immobilize the injured part during exposures of 20 minutes or more. Obviously, according to them, in busy clinics where many patients were handled in a single day, x-ray methods of diagnosis could never become practicable. Fortunately, there were tenacious advocates of the newly discovered principle who would not be discouraged by idle prophecies. Despite failures and the disheartening limitations imposed by the crudities of available equipment, an increasing company of physicians, often assisted by interested teachers in physics, tried and tried again to push forward the frontiers of x-ray diagnosis.

It must not be supposed that all the early attempts to see anatomic features beneath the skin surface resulted in x-ray images lacking in clarity and usefulness. Relatively thin parts, such as the fingers, toes, wrists, ankles and forearm, could be explored with brilliant success even with the most primitive types of equipment and with photographic plates intended solely for use with sunlight. In fact, one seldom sees today the fineness of bone detail that was commonplace in the days of gas tubes and glass plates, even though the tools of radiology have been immeasurably improved. Individual artistry, which alone enabled the pioneers of diagnostic radiology to maintain sustained interest in their work, is no longer essential. To a large extent, equipment now available has eliminated the personal factor; satisfactory over-all results are virtually guaranteed.

The expansion of diagnostic roentgenology from the status of an interesting hobby, practiced by a few sturdy souls with boundless confidence in its future, has taken place at a healthy rate, well attuned to the crescendo of accumulating scientific knowledge in all branches of medicine. X-ray diagnosis has outgrown its swaddling clothes and its flavor of mysticism and novelty. It richly deserves its present stature as an integral and essential part of the elaborate fabric of medical practice.

In the first decade of the twentieth century, x-ray apparatus was to be found only in hospitals and offices where worked and experimented those queer practitioners of medicine who derived a greater thrill from occasional triumphs in their hobby than

they experienced from the customary pursuits of doctors. This situation was modified enormously during and after World War I. Metallic foreign bodies and broken bones were matters of first-rank concern to the military surgeons, and in consequence the diagnostic toy underwent considerable and energetic development to meet wartime needs. In short order, advances were accomplished which might not have been expected for years to come. The first organized teaching of radiology as a specialty was hastily, though soundly, formulated under the direction of the Surgeon General of the United States Army. An army school was established at Camp Greenleaf near Chattanooga, Tennessee, with a faculty gathered from among those physicians who had steadfastly maintained their confidence in the ultimate recognition of the medical importance of x-rays. The *Army X-Ray Manual,* compiled for teaching in that school, survives in revised form to this day. Largely through the brilliant experimentation of W. D. Coolidge of the General Electric Company, unexpected and fundamental discoveries accelerated the development of generating equipment which could be taken into the field and operated effectively. The war helped the growth of radiology enormously, and radiologic methods were of incalculable value to military medicine. Many civilian doctors returned from the war determined to enjoy the benefits of x-ray diagnosis in their practices. The demand for an expansion of x-ray teaching continued and grew in the postwar period.

The third decade of this century found most hospitals with some sort of x-ray apparatus installed as an afterthought, usually in basement space. Only in recently constructed institutions was the new specialty housed more pretentiously in space better suited to the growing importance of its services. From the relatively narrow field of skeletal fractures, foreign bodies and chest examinations of primitive type, radiologic diagnosis had extended its repertoire to include virtually every aspect of physical diagnosis. Its reliability had been established on a high plane in gastroenterology, urology, chest diagnosis and neurosurgery, as well as in practically every other subdivision of medical practice. Dentistry had begun to incorporate its own particular application of the x-ray principle in its teachings and its practice. Improve-

ments in generating and accessory apparatus followed one another in rapid succession, closely and importantly paralleled by innovations in photography. The glass plates borrowed from commercial photographers had been replaced at the end of World War I by celluloid films. At first these were of poor quality and were difficult to process, but refinement followed refinement until the glass plate at last fell into complete disuse. Early in the history of x-ray diagnosis, contrast materials were employed to create unnatural and highly utilitarian differences in density within the body. These materials were tested, improved and supplemented with others which opened new fields of diagnostic achievement to the radiologist. By the time of Röntgen's death in 1923, medicine had amply demonstrated its willingness and ability to utilize his gift. The beneficial utilization of the biologic action of x-rays in many diseases had been sufficiently well proved to establish the principles of radiation therapy. The faltering beginnings of radiologic diagnosis had blossomed into a vigorously flourishing medical specialty.

At every milestone in the development of radiology, solemn prophets have appeared to announce that the ultimate exploitation of Röntgen's discovery has been accomplished. Thus far, all such pronouncements have been grossly inaccurate, because no sooner has the world been told that to look for further advancement will be useless than the tempo of inventive thought has increased and new radiologic methods have appeared to supplement or to replace still other aspects of medical practice. The end is not yet in sight.

The fifth decade of the twentieth century, including the fiftieth anniversary of Röntgen's discovery, witnessed a tremendous revival of interest in the mechanical and electrical perfection of radiologic apparatus. This is well exemplified by the photoelectric timing device developed at the University of Chicago and by the rapid refinement of procedure of photofluorography to which Hollis Potter and his associates gave impetus a few years earlier. Mass radiography of the chest was subjected to rigorous testing by the Army, the Navy and the Public Health Service; and millions of persons' chests were satisfactorily examined during the war years by means of the new method. Once

again, the peculiar demands of nations at war provided an impetus to accelerate the growth rate of medical radiology. Medical radiology had come to be more than a clinical medical specialty looming rather as a philosophy of medicine, a particular point of view to be employed advantageously in the attack upon almost every problem encountered in the practice of medicine. As such, it richly deserves the serious consideration of every member of the profession, for, no matter in what direction his particular interests may take him, no physician can escape the influence of radiology on his thinking and his reasoning.

A full sixty years after the discovery of x-rays, when diagnostic radiology has become very important in medical practice, widespread public concern has developed over the potential biologic dangers from radiations of all sorts. This concern, stimulated by the development of atomic weapons and by the expanding peacetime uses of atomic energy, has been sharpened by a deluge of reports, opinions and warnings from pundits of science, philosophy and the press. The situation calls for frank and unbiased assessment of the nature and the magnitude of the human hazards which attend the diagnostic use of x-rays.

Present concepts regarding the interaction between radiations and living cells and the relative radiosensitivity of various tissues are discussed in Chapter IX. It has long been accepted as fact that radiation exerts a deleterious effect on living tissues in proportion to dosage, although not necessarily in direct proportion. The rationale of radiation therapy rests on this concept; and international safety standards, inaugurated in 1925 and periodically reviewed and revised, safeguard patients and workers against radiation in excess of the maximum permissible dose. Although *all* radiation absorbed is harmful to living cells in some degree, it is fair to assume, in the absence of evidence to the contrary, that a threshold level, combining intensity and time, can be found below which such deleterious effects may be unrecognizable; this is the basis for the maximum permissible dose.

There are three major categories of radiation damage: (1) direct, local destruction or atrophy from heavy exposure; (2) premature aging and increased incidence of leukemia or other malignant tumors from radiation to which the entire body is

exposed, and (3) the production of undesirable mutations in reproductive cells as the result of cumulative absorption of radiation by the gonads. The first form of damage is inexcusable except in those instances where very large therapeutic doses applied locally are needed to control lethal lesions. It is to be remembered that the second form of damage relates to *total body radiation.* The dose known to be capable of inducing leukemia in mice, if applied to the entire animal, can be greatly exceeded without the development of the disease if part of the body is shielded. Undesirable effects of excessive total body radiation may appear promptly if lethal or slightly sublethal doses are received, but often the demonstrable effects are greatly delayed. Claims that the lives of radiologists may be shortened 15 days for every roentgen of total body radiation received by them are palpably and grossly in error, for it is estimated that by age 60 they may have received 1,000 or 2,000 roentgens. The lowest recorded dose related to demonstrable increase in the incidence of leukemia among the survivors of the Hiroshima and Nagasaki bombings was 50 r of total body radiation, a level not exceeded by the official maximum permissible dose since 1936. There is every reason to believe that radiologists have maintained protection precautions that are well within permissible limits in the matter of total body radiation except, perhaps, in the case of unborn children, where during the first few weeks and months of gestation the entire body can be exposed during purely topical exposure of the mother's abdomen.

The public has become most concerned over the possible genetic damage resulting from radiation which may not become apparent until the third or fourth generation beyond the exposure incident. It is important to realize that only that radiation which is selectively absorbed by reproductive cells can be effective in this direction and that there are vast differences between localized surface dosage, total body dosage and the dosage delivered directly to the germ cells in the gonads. Most children are born to parents whose ages do not exceed 30 years. Certainly, genetic damage after the reproductive period will not affect future generations in the slightest. It has been publically agreed by representative geneticists that an accumulated *gonadal* dose,

per person, of 10 r from conception to age 30 will not constitute a serious genetic burden to the race.

Exposures customary in roentgen diagnosis fall far, far short of values likely to accumulate to 50 r total body or 10 r gonadal in the case of any patient reaching age 30. It *is* important to limit sharply the exposure of the abdomens of women during the first half of pregnancy and to the bodies of infants and young children. All diagnostic procedures should be employed only when they are likely to serve useful purposes in patient care. In the hands of capable, certified radiologists the medical use of radiation need not be feared by patients.

The radiologic point of view in medical diagnosis embodies appreciation of the principle that, functionally as well as morphologically, the tissues and organs which comprise the human body can be investigated in situ and that the status of these structures can be expressed coherently in terms of relative density to a beam of x-rays. The freshness of view so essential to full utilization of the assistance provided by radiology can be sustained only if the underlying principle, rather than some isolated technical application, is kept in mind. To look on radiology as a stagnant, fully developed technic of medicine to be learned and then practiced by rote is to deny oneself the exhilaration of adding to dissection, microscopy and conventional physical diagnosis a collateral channel of approach to the complex riddles of medicine. The search for new applications, for combinations of other physical principles with those of radiology, provides gratification and spice to the daily round of clinical practice. The brilliance of today's accomplishments in medical radiology will become the commonplaces of tomorrow; it has been so since the beginnings of the specialty. Medicine must not hesitate to abandon individual applications the moment a better method becomes available, and the limitations of intellect alone will determine when progressive change will cease to occur.

BIBLIOGRAPHY

Biological Effects of Atomic Radiation: Summary Reports from Study by National Academy of Sciences (Washington, D.C.: National Research Council, 1956).

GARRISON, F. H.: *An Introduction to the History of Medicine* (4th ed., rev.; Philadelphia: W. B. Saunders Company, 1929).

GLASSER, O.: *Dr. W. C. Röntgen* (Springfield, Ill.: Charles C Thomas, Publisher, 1945).

HILLEBOE, H. E., AND MORGAN, R. H.: *Mass Radiography of the Chest* (Chicago: Year Book Publishers, Inc., 1945).

HODGES, F. J.: Fluorographic examination of the chest as a routine hospital procedure, Radiology 38:453–461, April, 1942.

——: The teaching of radiology, Radiology 45:599–564, December, 1945.

HODGES, P. C.: Development of diagnostic x-ray apparatus during the first fifty years, Radiology 45:438–448, November, 1945.

——: Health hazards in the diagnostic use of x-ray, J.A.M.A. 166:577–584, Feb. 8, 1958.

JONES, H. B.: A special consideration of the aging process, disease, and life expectancy, *Advances in Biological and Medical Physics* (New York: Academic Press, Inc.), Vol. IV (1955), 281–337.

NEEL, J. V.: The delayed effects of ionizing radiation, J.A.M.A. 166:908–916, Feb. 22, 1958.

REYNOLDS, L.: The history of the use of the roentgen-ray in warfare (Caldwell-Carman Lecture, 1944), Am. J. Roentgenol. 54:649–672, December, 1945.

RIGLER, L. G.: The development of roentgen diagnosis, Radiology 45:467–502, November, 1945.

ROENTGEN, W. K.: On a new kind of rays: Translations of Roentgen's original papers appearing in Sitzungsberichte of Würzburg Physical Medical Society on December 28, 1895, and March 9, 1896, Radiology 45:428–435, November, 1945.

SMYTH, H. DEW.: *Atomic Energy for Military Purposes: The Official Report on the Development of the Atomic Bomb under the Auspices of the United States Government* (Princeton, N.J.: Princeton University Press, 1945).

WARREN, S.: Longevity and causes of death from irradiation in physicians, J.A.M.A. 166:464–468, Sept. 29, 1956.

PART I

Diagnostic Radiology

utility of roentgenologic examination. Contrast materials in current use range from gaseous oxygen, carbon dioxide and room air for greater transparency to heavy metals in metallic state, or in the form of insoluble paste, emulsion or colloidal suspension, to impart unnaturally great opacity to actual or potential spaces within the body. Between these extremes a large and important group of substances has been adapted to, or especially devised for, contrast purposes, taking advantage of the relatively great density of the heavier halogens and the facility with which they can be synthesized into compounds which can be handled by various organ systems without effects which would be considered deleterious.

The versatility of roentgenologic examination of the human body is further enhanced by purposeful modification of the x-ray beam used and by selection of the recording medium best adapted to the particular diagnostic problem. The technic which produces the most enlightening information regarding the lungs and other soft tissue structures within and about the thorax is not suitable if one particularly desires to study the status of the ribs or the dorsal spine. Furthermore, technical modifications are necessary to compensate for differences encountered among patients. Great ingenuity and the skill acquired by long and patient experience are essential to the full and successful utilization of roentgenologic methods in the practice of medicine, which is to say that in this regard radiology has much in common with every other means of physical diagnosis.

The student will do well to remember that, however devious or elaborate the procedures employed by radiologists may appear to be, every maneuver is carefully planned to turn to practical advantage the basic principle that x-rays are selectively absorbed in direct proportion to tissue density. The accumulation of a considerable repertoire of devices to accomplish this represents the stock in trade of diagnostic roentgenology. There is no indication that the potentialities of the underlying principle have been exhausted, and no reason for physicians to be complacent with the present limitations of this method of exploring the human body.

Roentgenologic Equipment

The tools of diagnostic roentgenology which fifty years ago were crude and simple have, with the passage of years, become bewilderingly complicated and diversified. The conception and development of new designs to accomplish results of greater accuracy and scope with less dependence on the personal factor in the operation of apparatus have occupied the attention and energies of many physicists, engineers and equipment manufacturers for six decades. Despite the complex nature of modern x-ray diagnostic instruments, which is, after all, of concern only to those who must operate them, the tools used by the radiologists of today stem from the principles originally employed by Röntgen. Enlightened utilization of the medical evidence obtainable through x-ray diagnosis requires an understanding of a few fundamental physical and mechanical concepts. Detailed familiarity with the inner workings of complicated generating, controlling and utilizing mechanisms, by means of which x-rays are available for daily use, need not be acquired by medical students and clinicians who seek to learn what assistance the methods of roentgen diagnosis can give them in solving the numerous problems of medical practice.

The dislodgment of electrons from their customary orbits about the nuclei of atoms releases energy in the form of electromagnetic waves. Depending on the characteristic wavelength of these radiations, the invisible rays so produced exhibit the property of penetrating matter to a greater or lesser degree. To dislodge electrons and thus produce x-rays, it is necessary to replace them from an outside source by other electrons traveling at speeds which represent an energy level greater than the force which attracts the original particles to their parent nuclei. The bombarding electrons might be likened to projectiles; the dislodged electrons, to targets. How does one build a gun to fire such projectiles? When built, how can such a gun be aimed effectively? The answers to these questions are simple if one is content to accept them in language stripped of the imposing idiom and the inevitable formulas of physics.

Loosely bound electrons which wander between atoms within

masses of matter can be liberated from their casual captivity by raising the temperature of the mass. Once liberated, they will at once recombine with adjacent atoms—a phenomenon which can be controlled if the "sweating-out" process is conducted in a relative vacuum. The speed or energy of electrons so released is not sufficiently great to dislodge target electrons capable of generating x-rays. If, however, the newly freed aimless projectiles, each of which carries one unit of negative charge, are exposed to the repelling force of a high electrical charge of identical sign, and if the mass of target matter, also contained in the same vacuum chamber, is impressed with a similarly high energy of positive sign, the projectiles will be at once hurled and sucked true to the mark with a speed directly proportional to the magnitude of the impressed voltage. Here we have, then, a peculiar gun which with great accuracy automatically aims invisible bullets at equally invisible targets. To fire it we have only to heat a bit of metal wire and close a high-voltage circuit leading to electron source and target within a vacuum chamber. The flow of current within this circuit depends on the unit negative charges carried by individual electrons which travel from the negatively charged hot wire, or cathode, to the positively charged mass of target material, the anode.[1]

The most convenient and practicable means of providing the high electromotive force which activates the bombarding electrons is to increase the voltage taken from a commercial supply line at the expense of its current value. With alternating current passing at readily available voltages of 110 or 220 into the primary winding of a step-up or high tension transformer, the appropriately designed secondary coils will provide current at a voltage capable of imparting to the free electrons in the vacuum tube energies required to generate x-rays when they come to rest within the atomic network of the target mass. For practical purposes the full gamut of diagnostic procedures can be carried out with x-rays generated with a bombarding electron energy of 85,000 volts, or 85 kv. The heating of the wire cathode may be accomplished in a number of ways, all of them depending on the conversion of electrical energy into heat when

(1) For additional discussion of x-ray production see Part II, Chap. 9.

resistance to current flow is encountered. In actual practice a current driven by no more than 6–12 volts will liberate electrons in sufficient quantities for satisfactory tube operation. Target masses composed of relatively heavy elements are more efficient in the production of x-rays than those of lighter weight, and high

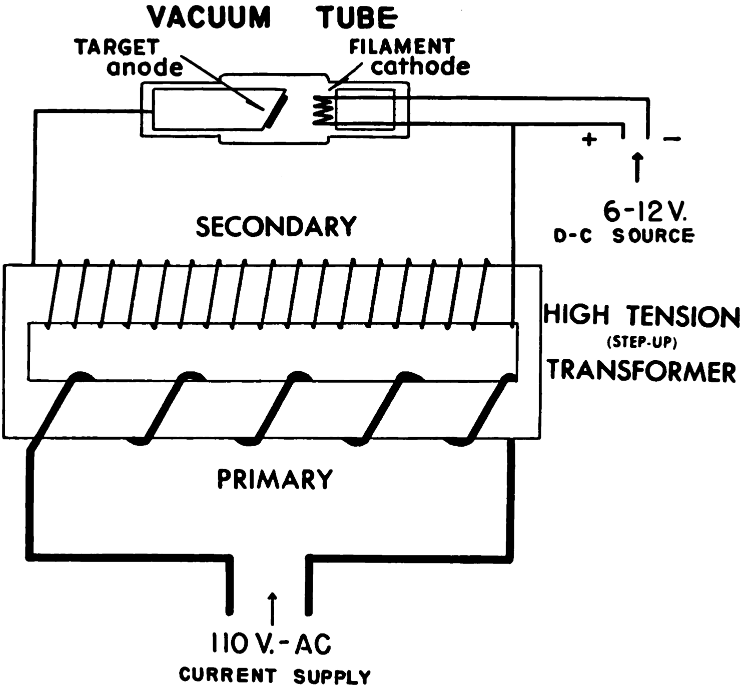


PLATE 1.—Diagrammatic representation of essential elements of x-ray generating apparatus.

melting point metals are desirable because they are resistant to the temperatures generated in the target mass as the result of electron bombardment. Many niceties which have been incorporated in x-ray generating equipment to control the performance of the essential elements are not necessary to an understanding of the basic principles and have been omitted from the illustrative diagram (Plate 1). The envelope surrounding the high-grade

vacuum within which electron bombardment takes place must be strong enough to withstand external atmospheric pressure, must be relatively transparent to x-rays of medically useful wavelength and must be electrically nonconducive. Here again the simplest design which incorporates all of these requirements has been modified cleverly to include greater sturdiness than that of the plain glass tubes originally employed and to incorporate shielding to prevent the escape of x-rays in any direction but the one to be used. The usefulness of tubes has been greatly extended by the design of features which concentrate the intensity of the portion of the beam to be used and which provide accessory means of preventing overheating of the target mass. These and many, many other innovations have resulted in progressive improvements in the efficiency of x-ray production, which in turn have been reflected in broader applications in medicine. The improvements in the fields of incandescent lighting and x-ray production are entirely comparable and are as readily understandable.

Röntgen first detected the existence of x-rays by observing and explaining the glow which they produced on a cardboard sheet coated with crystals of barium platinocyanide, a salt which has the property of fluorescence, or visible glowing, when acted on by short wave electromagnetic radiations or streams of high-speed electrons. He found that objects of relatively great density would cast shadows on such glowing screens placed in the path of the exciting beam. Sixty years later, radiologists, in the course of diagnostic endeavors, continue to peer at similar fluorescent surfaces similarly activated. Like Röntgen, they also use photosensitive surfaces to make records of their findings when permanency of the images is desirable. Procedures directly dependent on glowing screens carry the name "fluoroscopy" or "roentgenoscopy"; instruments devised for fluoroscopic examinations are known as "fluoroscopes." "Roentgenography," as the term implies, includes all types of x-ray examination which result in the production of permanent photographic images.

The earliest form of fluoroscope was a light-tight box or hood which the operator held before his eyes the better to see the dim glow of the fluorescent material on the inside of the end of

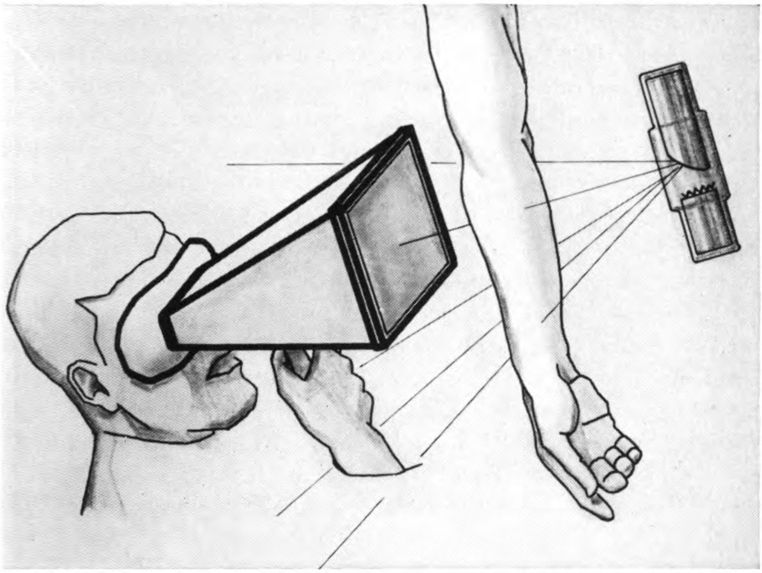
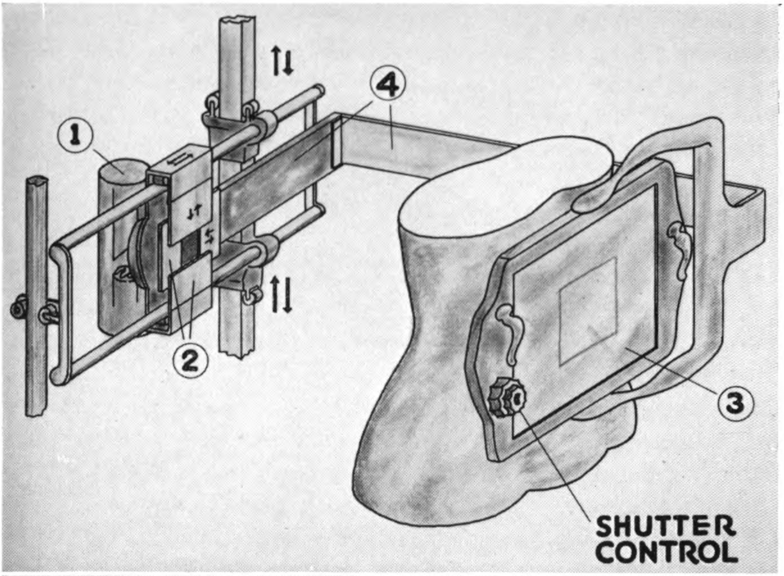


PLATE 2.—Earliest form of fluoroscope was a light-tight hood which the operator held before his eyes. Fluorescent material which glowed when exposed to x-rays covered inside of bottom of hood. Because deleterious effects of overradiation were not recognized, no protection against direct or stray radiation was provided. Source of x-rays, part to be examined and fluoroscopic screen were positioned independently.



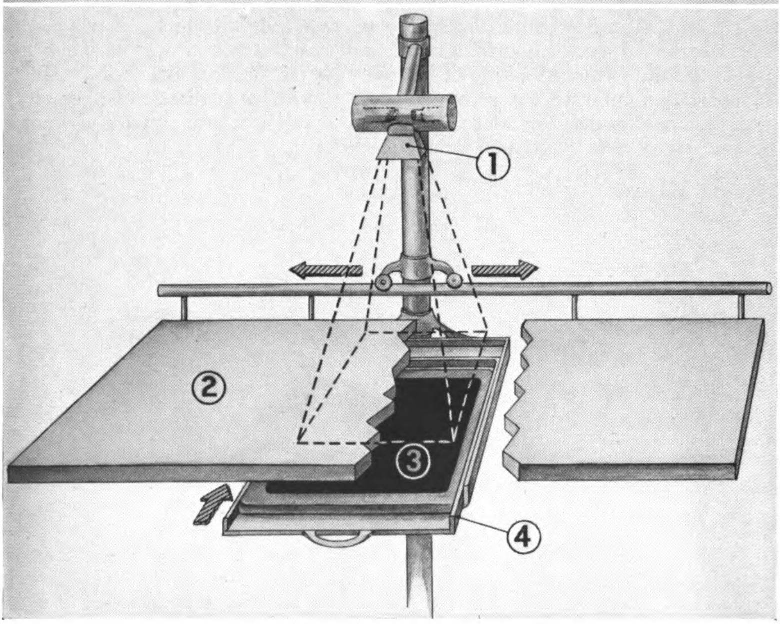


PLATE 3 (above). PLATE 4 (below).

the box when exposed to x-rays. Actually, this instrument was dangerous for patient and examiner alike. No provision was made to protect the patient from the exposure of much more of his body than that which could be examined at any one moment. There was no protection for the examiner from the primary beam of x-rays except the body of the patient, and no protection at all from scattered radiation.

Over the years fluoroscopic and radiographic apparatus have undergone phenomenal elaboration and refinement when compared with the homemade fluorescent cardboard and the glass "dry plate" so brilliantly used by the physics professor at the University of Würzburg in the winter of 1895. Steps have been taken to prevent the scatter of stray radiation for protection of patient and operator; adjustable opaque shutters have been devised to control the dimensions of the beam used for fluoroscopy, and holders with built-in fluorescent surfaces to multiply the photographic effect of x-rays on sheets of celluloid coated on *both* sides with extremely photosensitive emulsion are readily maintained in proper relationship to the body part being examined. X-ray tubes completely shielded against inadvertent electric shock can be adjusted with great nicety to proper position in relation to patient and film; mechanical devices, often power

---

←PLATE 3.—Basic mechanical principles of present-day fluoroscopes. *1*, x-ray tube heavily shielded to contain unwanted radiation, at the same time permitting useful beam to emerge by way of a small window fitted with filters of aluminum to reduce the effect of radiation on patient's skin; *2*, heavy sheet-lead shutters to modify size of x-ray beam; *3*, transparent lead-impregnated glass to protect observer against excessive exposure; *4*, rigid arm to which both tube and screen are attached. Counterbalanced and fitted with ball-bearing rollers, entire assembly is freely movable, side to side and up and down, on supporting framework. Fluoroscopes are built in vertical, horizontal and tilting types.

PLATE 4.—Basic mechanical principles of radiographic apparatus. Upright mast supported near floor and at table height by sturdy tubular rails, along which it may be shifted on ball-bearing rollers; an arm, adjustable along mast above table, carrying x-ray tube in protective shield; x-ray-proof diaphragm and "cone" (*1*) to limit size of beam to size of film to be exposed; radiolucent table top on which patient is placed (*2*); "cassette" or light-proof holder for photographic film (*3*) lined with fluorescent screens and having "window" opaque to light but transparent to x-rays, and drawer (*4*) for cassette, which, when closed, places film exactly in path of beam.

driven, readily adapt equipment elements to the comfort of the patient and to the needs of particular angles of projection which may be required or desirable. Such developments are no more than one would expect in view of the ever-increasing use of x-ray methods in the examination of patients. Plate 2 illustrates the primitive use of fluorescent screen and x-ray tube. Plate 3 presents a schema of the basic principle on which all modern fluoroscopes are constructed. Typical radiographic instruments are diagrammed in Plate 4. (No attempt has been made to reproduce actual illustrations of present-day equipment because obsolescence is too rapid to permit of completeness or accuracy.)

Present-day x-ray film is said to be "duplitized" because it is sensitized on both the front and back surfaces. When viewed in transmitted light the two images on the processed film re-enforce each other, making reduction in exposure time possible. By exposing film placed in cassettes, still further shortening of exposure is possible by squeezing fluorescent surfaces into very close contact with the surfaces of the film. In this way the image produced by x-rays directly is greatly enhanced by exposure from the "intensifying screens" (Plate 5).

The Potter-Bucky diaphragm, introduced in 1917, represents an innovation of such uniqueness and far-reaching practical importance that its principle deserves presentation in the interests of an application of its widespread use. The primary beam of x-rays which emerges from the generating tube is composed of rays which travel in unalterably straight lines in every possible direction from the source point. Within substances traversed by primary beams, secondary x-rays are produced; and these in turn travel in straight lines in all directions from the points of multiple origin. The secondary radiations, like the primary rays, are capable of casting shadows on the recording surface, and in doing this they blur silhouette margins to the point of preventing satisfactory visualization of deep-seated structures. Before 1917 the annoying effects of secondary radiation, noticeable in proportion to the total mass of tissue traversed by the primary beam, effectively prevented the satisfactory study of the vertebral column, pelvis, hip joints and many other parts, particularly

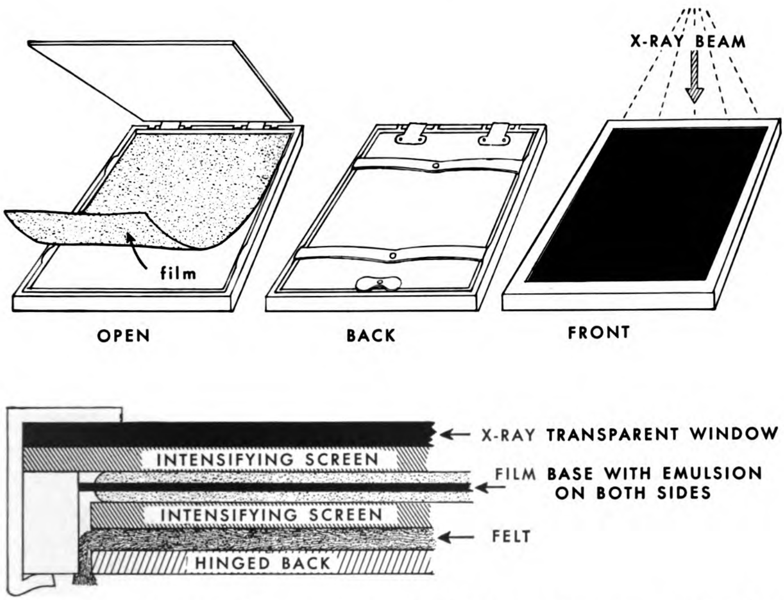


PLATE 5.—Diagram of exposure cassette. X-ray film has sensitive emulsion on both sides. To greatly enhance the photographic effects of x-rays, intensifying screens are used which emit visible light when exposed to x-rays. These screens must be in uniformly close contact with the film; the cassette must be light-tight, and the side closest to the x-ray beam must be made of x-ray–transparent material.

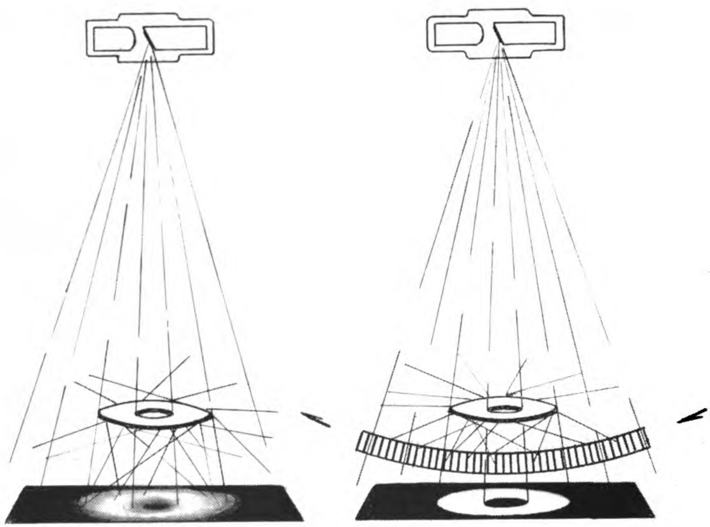


PLATE 6.—Principle of Potter-Bucky diaphragm. Photographed in beam of x-rays, opaque object casts a shadow, blurred somewhat by secondary rays generated when primary rays are absorbed. Secondary rays travel in all directions from source points, and their production increases sharply with increasing thickness or density of the object. Radially placed strips of lead, spaced with wood or other radiolucent substance, filter out angular secondary radiation while permitting most of the primary beam to reach film.

The diagram shows the original "curved" type of moving grid. Movement of the grid at uniform speed during the time of exposure effectively erased the linear shadows of the lead strips. Today both moving and fixed grids are used. In the case of the latter, which may have as many as 80–100 lines to the inch, grid movement is unnecessary because grid lines, though present in roentgenograms, can only be seen on very close inspection. For situations in which the production of annoying secondary radiation is particularly great, crisscross grids are available with lead strips in two layers, the one at an angle of 90 degrees to the other.

in obese patients. Dr. Hollis Potter of Chicago succeeded in constructing a device which achieved the selective filtration of secondary radiation before it could reach the film. Gustav Bucky had tried a number of schemes, each of which fell short of the desired complete elimination of secondary radiation without undue diminution of primary beam intensity.

The Potter-Bucky diaphragm, which absorbs 80 per cent of the undesirable smearing effect, revolutionized x-ray diagnosis by vastly expanding its sphere of usefulness. A grid made of thin lead-foil strips arranged radially, comparable to the axes followed by the straight-line rays from the x-ray tube, held on edge and separated by easily traversable wooden spacers, was designed for interposition between patient and film (Plate 6). A spring mechanism provided motive power to the grid, causing it to travel at uniform speed during the period of exposure so that the lead strips would not cast shadows to mar the appearance of the resulting roentgenogram. With the Potter grid, longer exposures were necessary to compensate, for the over-all interference of the filter to the primary beam; but this was a small price to pay for lucid and thoroughly practical images of deep-seated structures which, until the elimination of a large element of secondary radiation, had been unobtainable. Like other items of x-ray apparatus, the grid principle has been elaborated and improved without the introduction of any fundamentally different principles. Today the Potter-Bucky diaphragm is essential to the satisfactory employment of roentgen ray methods in many phases of diagnostic radiology. The appearance of the hip joint of a patient weighing 180 lb. without *(A)* and with *(B)* the use of the Potter grid is illustrated in Plate 7.

Three-dimensional vision, so valuable in everyday life for the appreciation of the true nature of solid objects, adds greatly to the analysis of roentgenograms of complicated structures in which the shadows of objects at various levels are superimposed on one another in a single plane. Film pairs prepared by shifting the x-ray tube parallel to the film surface between two otherwise identical exposures, thereby producing composite images of structures as they would have been seen at the fluoroscope by right and left eye respectively, can be used with success to

recapture the spatial arrangements of structures. It is necessary to view such films with an instrument which permits the right eye to see only the exposure intended for it at the same time that the left eye is viewing its particular aspect. Obviously, persons incapable of bifocal vision are denied the advantages of stereoscopic vision in roentgen diagnosis. It is imperative, of course,

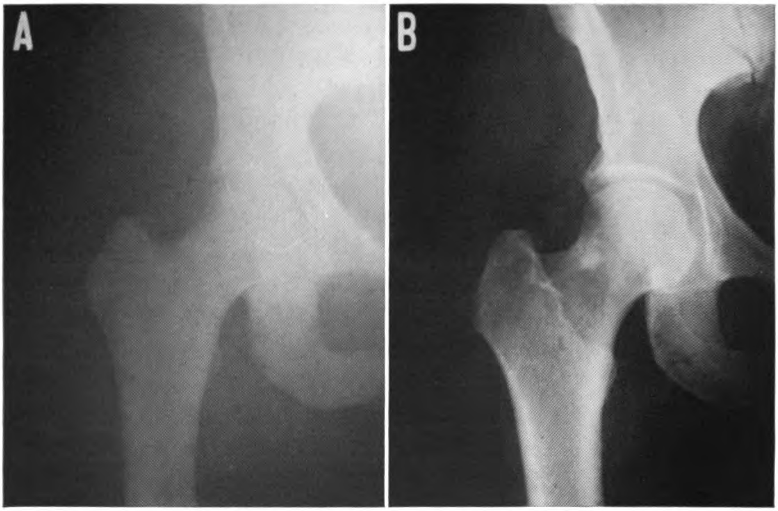


PLATE 7.—Roentgenogram of hip joint. *A*, without Potter grid; *B*, with Potter grid.

that the film pair be properly arranged for viewing if the three-dimensional effect is to be reconstructed. The beginner in radiology should refresh his knowledge of stereoscopy and should familiarize himself with the simple workings of stereoscopes used in radiology early in his approach to roentgen diagnosis. To fail to make proper use of this device is to deny oneself an extremely valuable asset in film interpretation. A surprising number of physicians seem content to meet the simple problem by remarking, "I can see more in single films," which usually means that they have never taken the trouble to acquire a simple skill whose use would serve them mightily and whose aid they can ill afford to forego. With a little practice it is possible to see stereoscopic film pairs in three dimensions without the use of optical equip-

ment if one learns to control one's powers of convergence without undue eye strain. Stereoscopy is of particular assistance in the analysis of roentgenographic reproductions of the anatomic structures of the skull and thorax.

It is difficult to pass by many ingenious manipulations of the fundamental elements of radiologic equipment. Clever mechanisms have been devised to capture and reproduce motion using a single exposure and a single film (kymography). Another device makes it possible to isolate selected levels within the body for reproduction while structures at neighboring levels are rendered virtually invisible by purposeful blurring (laminagraphy; also called tomography, planigraphy or body section radiography). Accurate measurement of angular distances between points within the body can be accomplished with specialized radiographic technics. The reader who wishes to explore these and other byways of roentgen diagnosis is referred to articles dealing with special technics which will be found in the reading list appended to this chapter.

The use of ordinary or cinecamera equipment for photographing images produced on fluoroscopic screens is called photofluorography. The success of this procedure depends on conversion of x-rays into visible light with a degree of efficiency which will result in light intensities sufficiently great to be recorded on available photographic materials. Although conversion losses are great, the scheme has been developed to the stage of thorough practicability in the case of chest examination and may well be useful in other fields. Since visible light can be refracted readily, images cast in something larger than natural dimensions by divergent x-rays can be photographed on film of much smaller size, thus reducing film costs and the labor of film processing. By the substitution of reflector lens systems for refractor optics, conversion losses from fluoroscopic surface to miniature film are greatly reduced. Photofluorography has been widely used in mass surveys of the chest.

To mechanize further the filming of chests in extensive survey projects, the phototimer has been used advantageously. Similar in principle to the light meters used in amateur photography, the timer used in photofluorography employs a vacuum tube

which converts the energy of light into an electrical current. The light allowed to strike the photosensitive element of the very efficient photomultiplier tube is metered by a condenser which, when fully charged, spills its potential into the grid of a thyrotron. Thus activated, the thyrotron valve passes a sufficiently large current from an outside source to a switch which interrupts x-ray production, thus terminating the exposure. The actual wiring of the device is more complicated than this brief description might indicate. In actual practice the timer begins to operate the instant the x-ray beam begins to illuminate the fluoroscopic screen. By trial and error the total density desired in the finished film is established, and the circuit of the timer is adjusted always to measure out the exact amount of light from the screen that will produce an identical degree of film blackening regardless of the thickness or density of the chest being examined. Automatic determination and interruption of exposure made possible by the phototimer represent a high point in technical development. The procedure has been well and successfully tested in actual practice in photofluorography of the chest and is being tried with promising results in all phases of diagnostic roentgenology.

The possibility that more brilliant fluoroscopic images might somehow be obtainable without increasing radiation exposure has long been an alluring prospect. In recent years the utilization of ingenious principles and devices borrowed from electronics has permitted this hoped-for situation to become a reality. Several image intensifiers have been devised in the United States and abroad, utilizing screens or phosphors capable of converting x-ray images into identical patterns of electrons. The electrons from the phosphor are greatly accelerated by means of electrical energy from an outside source, which causes them to strike a final viewing screen with greatly increased force, producing a correspondingly brighter image. Amplification ratios of 100:1 up to 1,000:1 have been achieved. One of the most recently developed devices uses the electronic pattern very efficiently as a closed-circuit television signal rather than to excite a viewing screen directly.

The original hope has not materialized practically, however, since the more brilliant screen images have not eliminated the

need for dark adaptation and viewing in a completely darkened room. Although daylight viewing is possible in the case of thin parts where contrasts are great, it is still necessary to use greatly subdued room illumination to see well when thick body structures are being examined. The body areas which can be covered with existing amplifying devices are annoyingly small and the equipment is bulky. Image amplification is not an unmixed blessing in the matter of reducing radiation exposure levels, for all too often an exaggerated feeling of safety leads to unduly prolonged observation and cinematographic filming. Despite inherent limitations of usefulness, the new systems promise very great advantages in the matter of fluoroscopic screen filming which is thoroughly feasible with a lens system of ordinary light-gathering capacity at relatively low radiation levels.

Roentgenologic Methods

Diverse and practical roentgenologic methods have been devised for the study of every part of the body. The specific procedures in common use are listed in anatomic arrangement in Table 1. The items listed as "Other" in each category include highly specialized or less commonly employed technics and particular adaptations of the x-ray principle to unusual problems of diagnosis presented by individual patients. Many of the examination types used can be planned as highly standardized procedures designed to provide reliable basic information. If and when routine x-ray methods are not applicable, or if it appears that diagnostic results might be improved by some alteration of standardized procedure, innumerable modifications can be devised by a resourceful radiologist or his technician.

In general, standardized examination methods are designed to permit the observer to survey the body part being studied. For example, standard or routine x-ray examination of the skull should include multiple exposures planned to show all or most of the cranial vault to reasonably good advantage. With the aid of films so obtained, it should be possible for the radiologist to inspect those structures which experience has shown are most commonly involved in fractures of various types, are affected in

TABLE 1.—INDEXING CODE FOR X-RAY EXAMINATION TYPES

SKULL AND BRAIN
10 Routine skull
11 Encephalography
12 Ventriculography
13 Intracranial angiography
14 Laminagram, cranial
19 Other

HEAD AND NECK
20 Paranasal sinuses
21 Mastoids
22 Orbit, foreign body, pilot examination
23 Orbit, optic foramen
24 Mandible
25 Temporomandibular joint
26 Soft tissues, neck
27 Sialography
28 Ocular foreign-body localization
29 Other

VERTEBRAL COLUMN
30 Splanchnic markers
31 Cervical spine
32 Dorsal spine
33 Lumbosacral spine
34 Scoliosis, pilot film
35 Scoliosis, complete survey
36 Routine spine
37 Myelogram
38 Laminagram, spine
39 Other

UPPER EXTREMITY
40 Fingers
41 Wrist, hand
42 Radius, ulna
43 Elbow
44 Humerus
45 Shoulder
46 Long-bone survey, child
47 Long-bone survey, adult
49 Other

LOWER EXTREMITY
50 Toes
51 Ankle, foot
52 Tibia, fibula
53 Knee
54 Femur
55 Hip, pelvis
56 Arthrogram
57 Femoral neck nail
58 Laminagram, skeletal
59 Other

CARDIOVASCULAR SYSTEM
60 Cardiac fluoroscopy
61 Cardiac kymogram
62 Cardiac films
63 Arteriogram, Seldinger
64 Venogram
65 Arteriogram
66 Aortogram
67 Splenoportogram
68 Angiocardiogram
69 Other

LUNG—THORAX—MEDIASTINUM
70 Fluoroscopy (no films)
71 Infant, to age 4 years
72 Routine, postero-anterior and lateral
73 Bones, grid, postero-anterior and lateral
74 Bedside chest
75 Bronchography
76 Frontal, lateral, oblique with and without grid
77 Foreign-body localization, operating room assistance
78 Laminagram, chest
79 Other

GASTROINTESTINAL TRACT
80 Fluoroscopy (only)
81 Abdominal scout films
82 Upper G.I.
83 Cholecystogram
84 Colon
85 Abdominal sinus tract injection
86 Cholangiogram, T tube
87 Cholangiogram, I.V.
89 Other

GENITOURINARY TRACT
90 KUB
91 Cystogram
92 Uterogram, tubal patency
93 Pregnant uterus
94 Pelvimetry
95 Pyelogram, I.V. or retrograde
96 Laminagram
99 Other

one way or another by intracranial tumors or are characteristically altered in appearance by a number of local and systemic diseases. To provide a satisfactorily complete opportunity to study the bones of the skull, many carefully planned exposures of the head must be prepared. In the case of long bones, a pair of exposures representing projections in the anteroposterior and lateral directions usually suffices. If the bone in question is deeply buried in soft tissues, standard procedure usually specifies the use of the Potter-Bucky diaphragm to enhance contrast by the elimination of secondary radiation. Whenever the thickness or third dimension of the part to be studied is relatively great, stereoscopic filming is highly desirable, and this is customarily stipulated in the specifications of the standard technic to be used. In the case of the gastrointestinal tract, routine examination should consist of a preliminary fluoroscopic survey followed by the preparation of roentgenograms which will record the appearance of stomach, duodenum and colon when these organs contain opaque material. In this field of x-ray diagnosis, minimum routine standards must be amplified according to the particular situations encountered in the course of screen examination. If there are no fluoroscopic indications to suggest the need for unusual time intervals between exposures or the wisdom of attempting to record particular structures which are not ordinarily included in gastrointestinal films, minimum or routine coverage will suffice.

Although in every x-ray laboratory where diligence is exercised to derive the maximum diagnostic value from radiologic procedures many ingenious adaptations of the roentgen-ray principle will be employed during the course of a year, the examination types which have been listed will greatly outnumber specialized or improvised technics. Resourceful radiologists, fully aware of the potentialities of the apparatus at their command and well practiced in its use, fall back on preplanned routine procedures to accommodate large numbers of patients and to facilitate the rapid handling of each day's work. They depend on findings so obtained to dictate further and more extensive methods of search when these are indicated. Physicians referring patients to a radiologist for his opinion can expect best results by explaining the diagnostic problem which exists, leaving the method of examination to the radiologist's discretion.

Interpretation of Findings

Interpretation of x-ray findings constitutes the major activity of the specialist in diagnostic roentgenology. Although long training and wide experience are essential if proficiency is to be attained in this field, it does not follow that roentgenograms need be inscrutable and meaningless to capable physicians whose activities are not confined to this specialty. However, it is not true that ability to interpret x-ray findings is a natural attribute of all physicians which requires no cultivation. The fundamental principles involved in deriving medical information of value from radiologic procedures are discussed here and illustrated in some detail throughout subsequent chapters of Part I.

Each adventure in the interpretation of x-ray findings may be compared to a trial in criminal court with the diagnostician assuming the roles of detective, prosecutor, judge and juror in succession and with impartiality. Clinical circumstances having aroused suspicion, roentgenologic evidence is sought and the fragmentary bits are collected, authenticated and pieced together to tell a coherent story in accordance with established medical fact and theory. The probable validity of the story thus developed is weighed in the light of previous experience, and the final verdict is recorded.

The cause of justice is elaborately safeguarded by detailed rules of court practice which do not permit of headlong haste or the introduction of hearsay evidence. To guard against superficiality of inspection and brashness of conviction, common causes of mistaken medical diagnoses, he who would interpret x-ray findings correctly must rely on self-imposed rules of procedure: *searching* observation followed by *unbiased rationalization* and finally a succinct *statement of opinion.* It is difficult, particularly for beginners, to make a habit of following this discipline; but the chagrin and embarrassment occasioned by a few avoidable, and therefore inexcusable, mistakes are potent persuaders.

Being as it is a purely visual method, roentgen diagnosis demands of its practitioners well-developed and diligently employed powers of observation. In the case of fluoroscopic images,

ability to observe accurately and effectively is a skill requiring much practice and strict adherence to inescapable rules of procedure which minimize the likelihood of error and insure reasonable safety to patient and examiner. The apparent simplicity and enticing practicability of fluoroscopy are entirely misleading and all too often engender unfounded self-confidence in untrained persons who fail to appreciate its shortcomings and its ever-present dangers. In the interest of his patients and himself, any physician who has not mastered the proper use of the fluoroscope should forego the temptation to dabble in its use, because, without adequate training and experience, he is apt to be misled by his observations, to miss important bits of information or to reap the bitter wages of irreparable biologic damage. On the other hand, without risking the dangers of fluoroscopy, reasonably well-developed ability to observe can be used to good advantage by any physician to detect significant alterations in the shadows of anatomic structures as recorded in roentgenograms. Familiarity with human anatomy as recorded by roentgen rays is of course imperative, but the translation of x-ray shadows into anatomic language is neither difficult nor impossible if one knows anatomy reasonably well. Deviations from the expected normal appearance and the relationships of various structures compare closely with those on which gross pathology depends.

It is not only possible but in many respects desirable to interpret x-ray findings in purely objective fashion with no advance information supplied by other methods of investigation. Although roentgenologic opinions regarding a given patient must be weighed and perhaps remolded in the light of data obtained from the medical history, physical examination and laboratory procedures, x-ray diagnosis is at its best when it stands to the fullest possible degree on its own merits. For this reason, if for no other, diagnostic roentgenology is practiced almost exclusively on a consultation basis. To avoid initial prejudices, the roentgenologist does well to begin his searching examination of films without knowing the opinions of other consultants. It is enough for him to know what part of the body he has been asked to examine and the tentative or provisional diagnosis of the

referring physician. Preconceived ideas have a habit of blinding the observer to unexpected evidence of the greatest diagnostic importance while lending undue or unjustified significance to minor anatomic variations which lie within the range of normal. X-ray diagnosis no longer is used merely to confirm suspicions aroused by other methods of approach; it has come to be a thoroughly dependable means of investigation in its own right.

The first step in the interpretation of x-ray findings, *searching observation,* means just that—means methodical inspection of all available x-ray images, fluoroscopic or radiographic. Speed will come with practice, but failure to drink in every detail of every image courts error. Much can be recognized almost instantly as the expected normal, permitting the eye to rove on to other features. One must learn to recognize even slight deviations from the normal and to carry these foward in building a final opinion. The most tempting and troublesome pitfalls responsible for most errors of omission are found in the guise of immediately obvious and often startling abnormalities that arrest one's attention and subsequent interest to the point of inhibiting the studied habit of scrutinizing everything in sight before permitting oneself the privilege of entertaining opinions. Speedy observation should be cultivated as a skill, but never at the expense of thoroughness. This is particularly true at the fluoroscopic screen, where accomplished performance requires that observation be closely succeeded by the evalution of evidence and the formation of opinion. Expertness in fluoroscopy is neither easily nor quickly attained.

Having completed to his satisfaction the task of gathering evidence and having jotted down those observations which represent known or suspected abnormalities of structure or function, the interpreter of x-ray findings should indulge in *unbiased rationalization*—should attempt to determine the meaning of the findings in terms of anatomy, physiology and pathology. This is a process of translation, the conversion of visual images of a particular sort into the language of medicine. With the accumulation of experience this translation will become free rather than literal, thereby gaining in clarity.

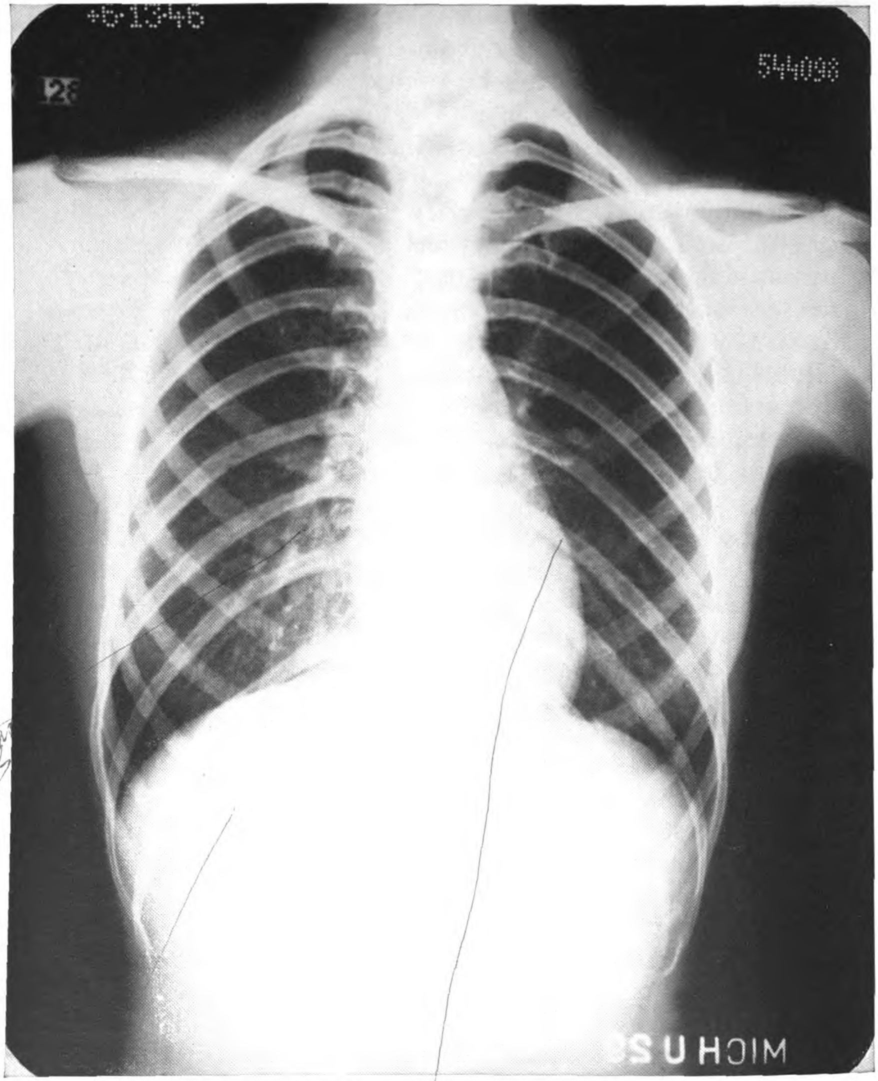
At this point let us pause in our discourse to try out the plan

of action we have been discussing. Examine the roentgenogram reproduced in Plate 8; it is at once recognizable as the x-ray image of a human chest. To be a source of medical information that will be useful in the interest of the patient it represents, it must bear some reliable and indelible identifying mark and it must be dated.

In the upper left corner the image of a perforated lead foil strip indicates that this film is part of the record of the 128th patient examined in radiology on June 13, 1946. The date was recorded on the film by perforation as it came from the dryer. At the time of interpretation the radiologist verified the patient's identity; and the correct institutional registration number, 544098, was perforated in the upper right corner to complete the reliable identification of this portion of the patient's record.

In the lower right corner of the reproduced chest film can be seen the images of lead characters imbedded in the bakelite front or window of the cassette which held the film. Because these characters appear in reverse as here reproduced, we may be sure that the film has been turned over for reading, for the lead characters are so placed in the cassette that it is impossible for them to be photographed in other than correct order, reading "Mich U 29." The number 29 identifies the particular cassette which was used in this case. The film was turned over for reading simply because for most people it seems more natural to consider the thorax as viewed from its anterior surface, whereas best results in chest filming are obtained when the x-ray beam passes through the body in the postero-anterior direction. In noting the appearance of the cassette marker, we have informed ourselves of the relation of patient to film at the instant of exposure. Thus far we have busied ourselves with the necessary, if relatively tedious, details of identification and orientation.

We need not consult this patient's hospital record to learn the sex, because the relatively faint shadows cast by the soft tissues which cover the bones of the thorax include the outlines of female breasts and tell us, in addition, that the patient is neither unusually obese nor emaciated. There are no asymmetrical swellings in the soft tissues, no included shadows of foreign bodies, no metallic articles attached to the clothing.



Calcified markings

PLATE 8.—Normal chest film. Exposure of patient no. 544098, the 128th examined at University Hospital on 6-13-46. Exposure in postero-anterior direction on film enclosed in cassette no. 29. Film turned over for viewing, so that patient's right side is on observer's left.

Diaphragm

heart

A common reason for examining the chest by x-ray methods is to search for evidence of pulmonary tuberculosis, but we have no valid reason to presume that the film we are studying was prepared for that reason. We have no right to neglect any structure which is represented as we proceed with our inspection. To be sure that we do not overlook anything that may be of importance, let us turn our attention away from the highly transparent zones where the lungs can be seen to the best advantage and look at the contours of the leaves of the diaphragm. They are smoothly curved, as we would expect, and stand out in sharp contrast with the lungs. The costophrenic sulci are clearly defined, as they should be, and the right half of the diaphragm lies higher than the left in about proper degree. Step one of our survey has been completed without the discovery of any significant abnormality.

If we now fix our attention on the shadow mass which extends from diaphragm to thoracic inlet, it is not difficult to identify the cardiac apex between the anterior portions of the fifth and sixth ribs some 5 cm. from the lateral chest wall. The gentle curvatures recognizable along the left margin of the mediastinal shadow correspond in position and form to ventricular wall, first portion of the pulmonary artery and contour of the aorta in its transverse portion. Along the right margin little of the heart shadow is to be seen beyond the relatively dense vertebral column. Above the aortic shadow a vertical midline band of lesser film density can be identified as the air column within the trachea. The mediastinal shadow has been explained on the basis of anatomic structures which appear to be of normal proportions and in their customary positions. We have found nothing to indicate that there is anything unusual about the mediastinum.

As a third step in our critical survey of the status of this thorax as recorded roentgenographically, we should inspect the skeletal parts which can be seen. From the base of the neck we turn our eyes either to right or to left to the first rib. It is easy to follow its entire course, observing its width, its relative density and the details of its contours. In succession we repeat the process for the visible portions of each of the ribs below it, always

beginning at the vertebral end, and in less time than it can be stated in words we are able to assure ourselves that, as far as x-ray appearances are concerned, none of the ribs on this side of the body appear to be abnormal. The same type of inspection on the opposite side convinces us that all the ribs are normal, and we finish this phase of the inspection process by glancing at the clavicles, the visible parts of the scapulae and the humeri.

Still choosing to ignore the lungs for the present, we pay attention to the shadows clustered close to the mediastinum between posterior portions of the fifth and eighth ribs. Here, in the position of the hilum of the lung, one must expect to find shadows cast by structures which constitute the supply lines over which air, blood and lymph flow to and from the highly specialized respiratory portions of the lungs. These shadows are visible against a background provided by air-inflated pulmonary tissue because arteries and veins are filled with blood which is considerably more dense than air and lymph vessels and nodes are filled with a similarly dense fluid. To a lesser degree, the compact walls of bronchi are responsible for visible streaks against the lung in the background. For some peculiar reason beginners in the practice of chest film interpretation find it difficult to make proper allowance for these shadows at the pulmonary hilum and feel impelled to ascribe dire pathologic significance to them in every instance or at least to hint darkly at the possibility of such significance. In the present case we observe that the somewhat poorly defined zones of impaired transparency conform in location to the points at which the major bronchi enter the lungs. We see, further, that the shadows fade out into lung, as we would expect with the normal divergence of airways and vessels; that the heart covers a good deal of the shadow on the left, thus imparting apparent prominence to its fellow on the right. Lastly, if we observe closely, we can identify in part the contours of individual channels which divide into smaller and smaller branches. In this case at least we have been able to lay the ghost which so often frightens observers into reporting "increased hilum shadows," "hilum lymphadenopathy" or, what is even less excusable, "peribronchial fibrosis," "chronic bronchitis" or "chronic upper respiratory infection." This last diag-

nostic gem is a masterpiece of ambiguity which seems to imply the existence of a smoldering inflammatory process mysteriously related to repeated "common colds." The hilum shadows here reproduced are perfectly normal and easily explainable in terms of normal anatomy.

Now, at what seems to be long last, we can come to the *pièce de résistance*, the lungs and their pleural coverings. In the majority of instances, but by no means exclusively, chest roentgenograms are prepared for the purpose of searching out signs of pulmonary disease. We have done well to assure ourselves that in every other respect the film which we are inspecting is barren of pathologic interest before we turn to the consideration of the lungs. To make our task simpler in this demonstration of methodical inspection, we shall mask out the distracting shadows already scrutinized (Plate 9) and study that almost transparent part of the film, crisscrossed by rib shadows, in which will be found little else than the delicate, lacelike tracery of small vessels recorded against transparent inflated alveolar lung tissue. Here again let us do our task methodically by forcing our eyes to rove over each square inch of unmasked space lest we miss deviations from the normal which, though unobtrusive, may well be of great clinical importance. Finding nothing to mar the sameness of the lung pattern, we may be satisfied that there exists no pathologic condition capable of detection by the method we are using. In the case of this sample roentgenogram our search for evidence is completed; we have complied with the demand for searching observation and are ready to indulge in unbiased rationalization of our findings.

In this instance, having produced no damaging evidence, we, as prosecutor, can build no case against the suspect unless new evidence is available from some other source. It may be that the use of x-ray procedures other than the single postero-anterior projection at our disposal would have turned up significant signs of disease. It may well be that this patient is suffering from an ailment which does not produce recognizable roentgenographic signs. This process of rationalization, simple in the present circumstances, is important none the less and becomes increasingly important if evidences of pathologic processes have

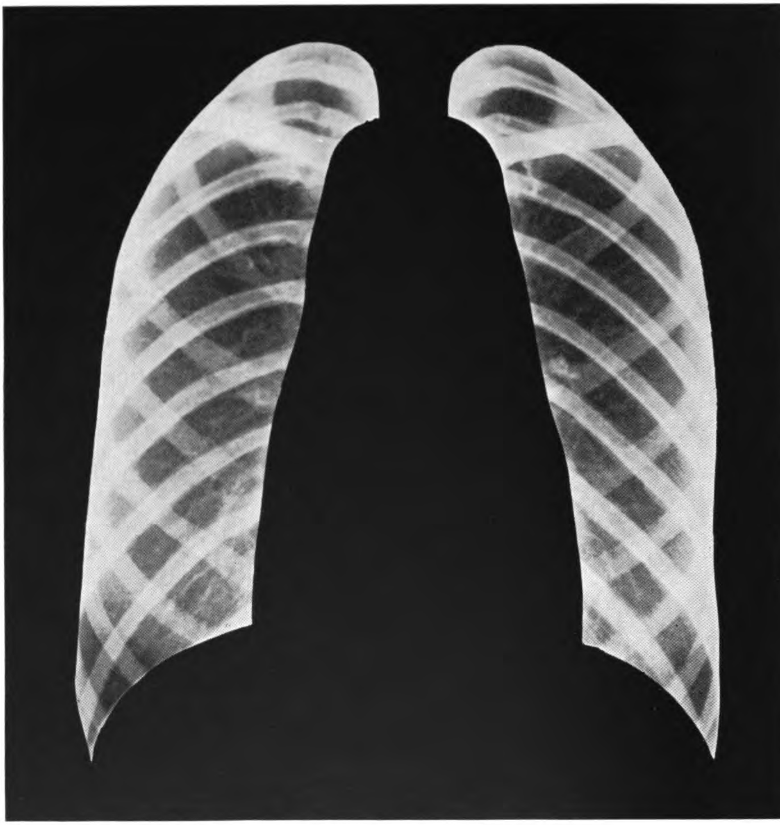


PLATE 9.—Normal chest film (same as Plate 8) fitted with an opaque mask to cover the mediastinum, the hila and all extrathoracic structures. Such masking enables the observer to concentrate attention on the all-important lung parenchyma. An experienced radiologist can accomplish the same result without actual recourse to masking.

been uncovered. The "opinion" to be rendered by the radiologist should be flavored by such processes of reasoning. The reporter should carefully differentiate between fact and opinion in presenting his conclusions.

In stating our opinion of the film we have been analyzing, we might employ numerous qualifying clauses to indicate the many considerations weighed; but in the interests of brevity and succinctness it would be preferable to write, "Negative for x-ray evidence of abnormality." In actual practice this may allowably be compressed still further to "Negative Chest" if everyone concerned in the examination understands this to mean that every aspect of the routine-type film has been studied without the discovery of recognizable abnormality.

The rationale and technic of film interpretation have been presented at length in the hope that lessons will have been learned which apply to the analysis of *all* roentgenograms. Any roentgenogram, however complicated and baffling in appearance at first glance, is susceptible to some solution if the principle of "divide and conquer" is applied. Something is learned if only the part of the body and the direction of projection have been determined, for this is a prime requisite of full appreciation of the situation. More is gained if the observer can say whether the parts shown appear normal or abnormal, even though the nature or meaning of abnormalities, if present, may be entirely obscure. It is an accomplishment to be able to describe the deviations from normal and to be reasonably certain that all particulars of the abnormal findings have been detected. If, through the process of rationalization, the observer can supply in his opinion an exact identification of the disease processes involved, the very pinnacle of achievement has been reached. He hopes to reach that pinnacle in the case of every roentgenogram he examines, but is well content to reap from his study any diagnostic information which will be helpful in solving the patient's problem. The methods of roentgen diagnosis have very real limitations. It is well for those who use them to learn and to appreciate the extent of these limits of usefulness.

Recording of Findings

Reporting findings and opinions represents the final step of an x-ray consultation. Important as it is for the radiologist to consult verbally with his professional colleagues regarding the x-ray findings in their patients and to discuss their probable significance in the light of information derived from other sources, this is not enough to satisfy the demands of good medical practice. Radiological findings and opinions must be entered in written form in the patient's clinical record. Annoying and boring as it often proves to be to physicians, record keeping—good record keeping—is an inescapable responsibility attached to the practice of medicine.

From the legal, as well as the purely professional, point of view, roentgenograms must be preserved as clinical documents, together with written statements setting forth the extent to which x-ray evidence has been used in the diagnosis and treatment of the patient's ailments. It is best to convert the results of radiologic deliberations to written form at the time each patient's situation is being weighed. This should not be considered a pure nuisance, a necessary evil, because, faced with the task of putting evidence, rationalizations and ultimate opinions or impressions into written form, one is less likely to indulge in loose and casual thinking. If one looks forward to reviewing clinical experiences at some future time, it would be well to follow some form of cataloguing or presorting of case material by diagnoses or roentgenologic impressions and to do this while each individual diagnostic problem holds one's full attention. This is much more effective and far less laborious than to attempt to sort material by diagnoses after the volume of records has grown to large proportions. Here, too, a daily nuisance conceals a virtue, for the cataloguing of diagnoses or impressions requires that statements be carefully considered and that they conform to acceptable medical usage. All told, written and catalogued medical records are apt to contain terse, well-considered and reasonably accurate observations and opinions. Their value is enhanced by the use of language carefully purged of all ambiguity.

Plate 10 represents an acceptable typewritten report of the single frontal projection of the chest which is reproduced in Plate 11. Note that the name of the patient, together with the appropriate registration number, the date of examination and other identifying data, is entered at the top of the report sheet. The report itself is preceded by a greatly condensed statement of the reasons for the examination. The body of the report is devoted to the description of findings. Whenever structures specifically under suspicion have been found to appear normal, this information is included; otherwise, by mutual understanding among all staff members, the listing of normal findings is omitted in the interest of brevity. In this particular report the difficulty experienced in arriving at a specific conclusion in the rationalization of the x-ray evidence is expressed in a separate paragraph designation "Discussion." This device is employed only when the relationship of observations to opinion as finally expressed seems to require explanation or clarification. Under the heading "Impression," prominently set off by the use of capitals, each conclusion, defensible on the basis of roentgenologic observations in their relation to clinical information from other sources, is listed by number.

You are urged to read this sample report carefully, referring directly to the reproduced roentgenogram, in order to observe with what faithfulness the written account captures the objective evidence presented by the film and builds it into a plausible opinion. For the sake of brevity and the conservation of clerical time and effort, radiological reports might be limited to the impression alone; but terse reporting of that sort does not imply that careful observation and rationalization based upon such observation can be avoided if final opinions are to be sound.

The disposition of typewritten x-ray reports deserves mention. The original copy should be filed permanently as an integral part of the patient's record, whether this be kept in a physician's private office, the files of an outpatient clinic or in a hospital record division. A great deal of lost motion can be avoided in reviewing the results of previous examinations when patients are again referred to the radiologist if carbon copies of reports are routinely stapled to corresponding consultation requests and

UNIVERSITY OF MICHIGAN

UNIVERSITY HOSPITAL

DATE	LOCATION	SERVICE
Feb. 4, 1958	OPD	Med.

CONSULTATION REPORT
Department of Radiology

Sex M. Age 46

Referred by: Dr. Smith

Reg. No. 891488

Name Blissfield, Arthur L.

X-Ray Examination of the Chest

Provisional Diagnosis: Pulmonary lesion reported on admission photofluorogram.

The thoracic aorta is slightly elongated. The heart is not enlarged. Surrounding the right coracoid process there is seen tufted, somewhat mottled bone proliferation representing a benign osteochondroma. The LEFT lung is normal in appearance.

In the RIGHT lung there is a 2½ cm. spherical mass at the fourth anterior interspace. This mass is discrete, sharply defined, with no indication of lime salt content. No other abnormality is observed.

DISCUSSION: Granulomas of various types may present this appearance, as may primary bronchial neoplasms and some benign pulmonary neoplasms. In this instance differential diagnosis cannot be made on the basis of x-ray findings alone.

IMPRESSION: 1. Solitary nodular mass, 2½ cm., mid-lung right. Primary bronchial neoplasm suspected. Resection advised.

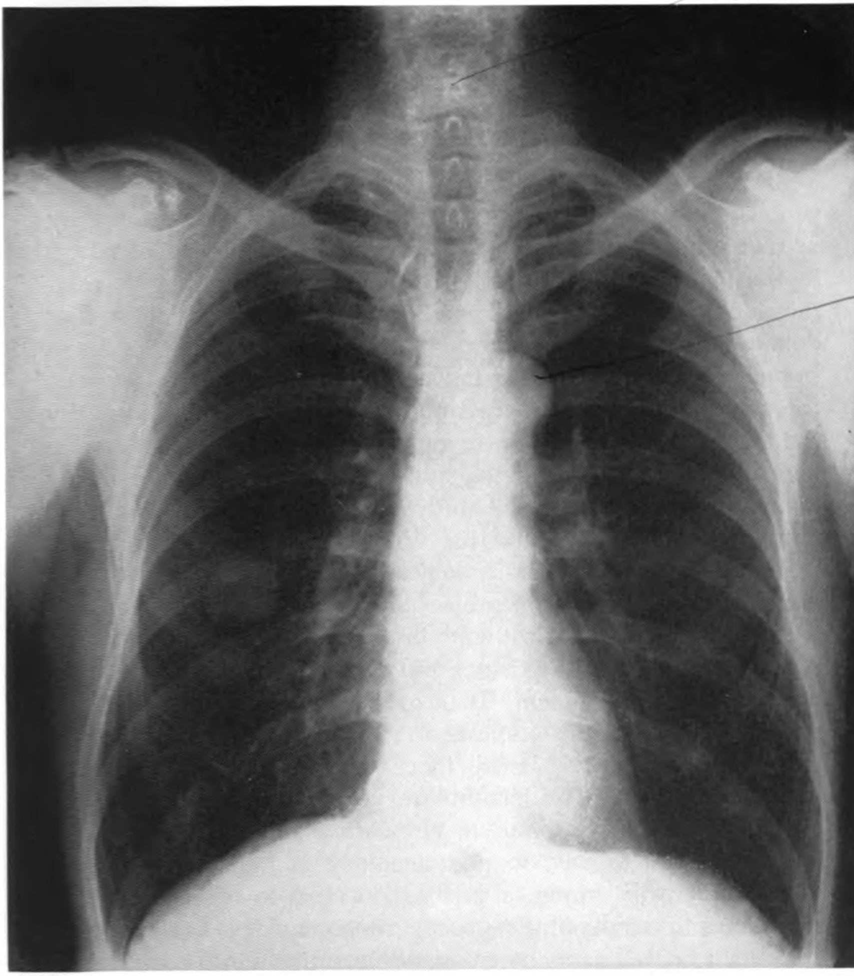
2. Benign, clinically unimportant osteochondroma, coracoid process, right scapula.

H. H. Jones, M.D.

72 - 724, 403

PLATE 10

vertebral column



Aortic notch

PLATE 11.—Abnormal chest film. (See consultation report, Plate 10.)

filed directly with the patient's films in a master portfolio which is clearly identified as belonging to that particular patient.

Position in Medical Profession

The position of diagnostic roentgenology in the medical profession is one of intimacy and importance. Defined formally as that subdivision of radiology concerned with the use of x-rays in the field of medical diagnosis, one soon learns that its relationship to the practice of medicine is far broader than that definition implies. Very properly it may be thought of as a branch of anatomy, occupying a position somewhere between the spheres of its classic gross and microscopic subdivisions. By the same token, diagnostic roentgenology may be considered a logical phase or aspect of the subject of pathology, for certainly it does constitute a means of studying expressions of disease even though the tools used and the criteria on which opinions are based are different. Just as logically the roentgenologist may claim close kinship to the subject of physical diagnosis, because with his peculiar methods and instruments he delves into the physical qualities of the tissues and organs of the body in search of medical enlightenment. To a greater or lesser degree, diagnostic roentgenology is enmeshed in the activities of many other well-established fields of medicine: it contributes to biochemistry in the study of mineral metabolism; to physiology by adding to our knowledge of respiration, circulation and the behavior of gastrointestinal organs; to pharmacology in portraying the responses to many forms of medication, and to other fields too numerous to mention. Diagnostic roentgenology has come to belie its accepted name by co-operating actively in the treatment of disease. This is well expressed, for example, in the close dependence on changing x-ray findings seen in the practice of thoracic surgery and in the medical management of pulmonary tuberculosis and peptic ulcer.

The full and efficient use of x-rays amply justifies continuation of the practice of developing in certain physicians particular proficiency in the use of radiologic apparatus as well as keen ability to make the most of its medical potentialities. Roent-

genology's sphere of influence in the medical profession is still expanding vigorously. Departmentalization should not and must not be carried to the point of erecting and maintaining barriers which cloister the radiologist and permit him to neglect his broad responsibilities as a physician. Because the daily use of x-rays involves the maintenance of highly specialized equipment and the organization and direction of trained nonprofessional workers, the delegation of roentgenologic affairs to a designated group of physicians is desirable and fully justifiable. Clinical investigations which involve radiologic technics will move along more rapidly and more smoothly if they are planned and carried out by men fully trained and widely experienced in their use. In every important aspect—clinical practice, teaching and investigation—roentgenology justifies its right to departmental status, but the boundaries seeming to confine it are elastic and permeable.

The American Board of Radiology, established in 1934, has drawn up regulations defining the minimum training required of physicians who desire to present themselves for examination leading to certification. Graduation from an accredited medical school, the completion of at least twelve months of internship in an accredited hospital and three years of postgraduate training are required plus one year of extended training or one year of practice in the specialty. Postgraduate training must include instruction in physics, anatomy, pathology, roentgen diagnosis and radiation therapy. If, with this prescribed training, the applicant is a member in good standing of the medical society in his locality, he is permitted to take examinations covering the various phases of the entire subject. Successful performance in the examination leads to certification which marks the holder as one who has been found proficient in the specialty. Since its establishment in 1934, by July 1, 1957, the American Board of Radiology had certified 5,581 physicians in some branch of radiology.

READING LIST

Andrews, J. R.: Planigraphy: Introduction and history, Am. J. Roentgenol. 36:575–587, November, 1936.

Chamberlain, W. E.: Fluoroscopes and fluoroscopy (Carman Lecture), Radiology 38:383–413, April, 1942.

Hirsch, I. S.: The recording of cardiac movements and sounds by the roentgen ray (kymophonoroentgenography): Part I, Radiology 22:403–422, April, 1934.

Hodges, F. J., and Lampe, I.: Filing and cross-indexing roentgen-ray records, Am. J. Roentgenol. 41:1007–1018, June, 1939.

Jarre, H. A., and Teschendorf, O. E. W.: Roentgen-stereoscopy: A review of its present status, Radiology 21:139–155, August, 1933.

Morgan, R. H.: Screen intensification: Review of Past and Present Research with Analysis of Future Development, Am. J. Roentgenol. 75:69–76, January, 1956.

Potter, H. E.: Diaphragming roentgen rays: Studies and experiments, Am. J. Roentgenol. 3:142–145, 1916.

3

The Head

TO THE STUDENT beginning the study of roentgenology, the skull and its contents may appear to present more baffling diagnostic problems than any other anatomic section of the body. His immediate reaction may be one of complete bewilderment tinged with resentment that such an approach to the subject of roentgenologic diagnosis is both irrational and unfair. This attitude is understandable if one considers the complex anatomy of the head and the many confusing shadows which appear on roentgenograms of this region. The multiplicity of views employed by the roentgenologist to offset these bothersome shadows may, at first glance, appear to add to the confusion. Distortion of an anatomic part resulting from intentional oblique or tangential projection of an x-ray beam makes the very real difference between "x-ray" anatomy and "cadaver" anatomy even more evident than conventional anteroposterior and lateral roentgenograms. Nevertheless, if the student will take the short time necessary to familiarize himself with the various projections used in examining the different portions of the head, much of the mystery surrounding roentgenologic diagnosis of these parts will fade into insignificance. Furthermore, he will find to his pleasure that disease entities which manifest themselves in and about the skull produce roentgenographic signs that, on the whole, are more specifically diagnostic than those produced by disease processes in most other portions of the body. Apart from

anatomic convenience, this fact in itself would seem to justify the selection of the head as the logical starting point in discussion of roentgenologic diagnosis.

Because roentgenograms of the face bones and adjacent structures constitute such a complex network of overlapping osseous ridges and because the cranial vault is a globular structure, stereoscopic views are virtually essential for proper appraisal of these parts. The paranasal sinuses, mastoids, orbits, mandible, etc., are seen to best advantage on stereoroentgenograms especially designed to reduce to a minimum the overlapping of bone shadows. Satisfactory study of the vault requires projections in right and left lateral as well as in the sagittal planes.

THE PARANASAL SINUSES

The paranasal sinuses are paired, air-containing cavities within the maxillary, frontal, ethmoid and sphenoid bones. In general, only the maxillary sinuses are recognizable in the newborn period, at which time they are seen as tiny, vertical slits adjacent to the lateral borders of the nose. As growth progresses, these maxillary antra gradually assume their characteristic pyriform shape in a bilaterally symmetrical manner. Occasionally one or both may be markedly underdeveloped, in which event one must be careful not to mistake the developmental anomaly for significant disease.

The ethmoid sinuses are comprised of a large group of small cells located between the orbits and the upper portion of the nose. They are present at birth but are so small that evaluation by roentgen methods is not practicable until the fifth or sixth year. It is customary to subdivide the ethmoid cells into anterior, middle and posterior groups, although no well-defined dividing lines can be discerned.

The frontal sinuses, when well developed, are found just above and medial to the orbits. They pneumatize slowly from below upward, reaching the level of the orbital roofs at the age of seven or eight. These air spaces, seldom truly symmetrical, show wide developmental faults varying from complete absence to huge anomalous cells which occupy a third or more of the

entire frontal bone. Frequently these sinuses extend posteriorly into the orbital roofs, and in this location they are difficult to distinguish from anterior ethmoid cells.

The sphenoid bone may contain centrally placed single or paired cavities, depending on whether or not a highly variable median septum of bone is present. As a rule the sphenoid sinuses do not begin to pneumatize until the third or fourth year, and then they usually do so in an asymmetrical manner.

It is generally agreed that x-ray examination represents the most accurate method for the detection of paranasal sinus disease, but individual interpretation of roentgenograms is subject to wide variation. For this reason it is especially important to distinguish between factual information depicted by the films and an opinion based on a correlation of clinical and roentgenologic findings. This is practically axiomatic in regard to the entire field of roentgen diagnosis but is particularly pertinent in regard to sinus disease. Accuracy of diagnosis depends to a large extent on the technical quality of the roentgenograms and, within reasonable bounds, on the number of different projections used in the examination.

[The Paranasal Sinuses *continued on page 66.*]

At University Hospital a routine survey of the paranasal sinuses consists of the exposures mentioned below and illustrated in Plate 12.

Waters projection (Plate 12, *A*).—This is the most useful of all sinus projections. It affords one an opportunity to survey frontal, ethmoid and maxillary sinuses on the same roentgenogram. (*1*, frontal sinus; *2*, ethmoid sinuses; *3*, orbit; *4*, nasal septum; *5*, maxillary sinus.)

Caldwell projection (*B*).—Distortion of the frontal sinuses which inevitably occurs in the Waters position is avoided by this projection. The ethmoid cells also are seen to good advantage, but the maxillary antra are partially hidden by the petrous portions of the temporal bones. (*1*, frontal sinus; *2*, ethmoid sinuses; *3*, orbit; *4*, nasal septum; *5*, petrous bone.)

Granger projection (*C*).—This view is included on the same film as the Caldwell projection. Further opportunity to study frontal, ethmoid and sphenoid sinuses is afforded, although there is considerable overlapping of these structures, (*1*, petrous ridge; *2*, overlapping sphenoid and ethmoid sinuses; *3*, maxillary sinus; *4*, nasal septum; *5*, mandible.)

Axial projection (*D*).—This exposure is made primarily to show the sphenoid sinuses, but the maxillary antra, the mandible and the structures at the base of the skull also are well seen. (*1*, maxillary sinus; *2*, mandible; *3*, sphenoid; *4*, foramen ovale; *5*, mastoid; *6*, foramen magnum.)

A single lateral projection of the skull (Plate 18, *B*, p. 84) is included in the routine sinus examination but is of little value in its own right because of direct overlapping of opposing sinuses. This view is of diagnostic assistance only when considered in conjunction with the sagittal projections.

With such a group of roentgenograms available for careful study, it is possible to detect certain deviations from the normal which indicate the presence of disease. Some of the more significant changes are worthy of the medical student's attention.

Ethmoidal Sinus
Frontal Sinus

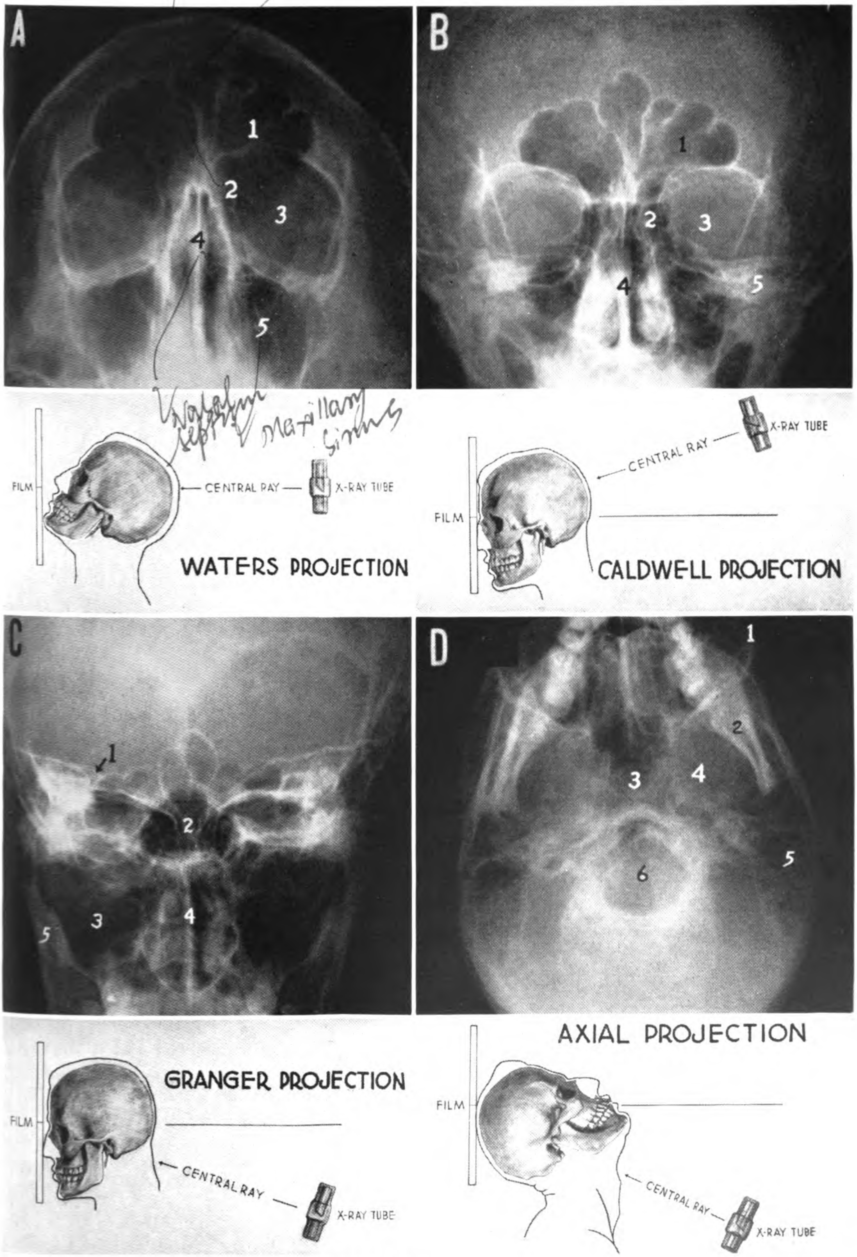


PLATE 12

CLOUDING. The convenient term "clouding" is used to designate any uniform encroachment upon the paranasal sinuses which causes generalized loss of their normal radiolucency. Pronounced clouding of one or more sinuses is clearly evident, whereas mild haziness is much less readily identified. In this regard a useful rule of thumb is that, since the sinuses normally have a density approximating that of the orbits, the radiolucency of the latter may be used as a rough guide to determine whether or not clouding of the sinuses is present. In unilateral disease, comparison with the opposite (normal) side usually is helpful. For example, in *A* (Plate 13), the right maxillary antrum is homogeneously clouded, whereas the left antrum is apparently clear. The frontal and right ethmoid sinuses in this patient show minimal haziness. The left ethmoid cells, only a part of which are seen, appear clear.

Clouding may be due to inflammatory exudate, hemorrhage, neoplasm or edematous mucous membrane lining the sinus cavity, and it is impossible to distinguish between these various entities by x-ray examination alone. When the sinus is incompletely filled with fluid, films exposed with the patient in an upright position may show a fluid level, as in the left frontal sinus in *B*. Clouding of the left ethmoid and maxillary sinuses is also evident in this particular patient.

THICKENING OF MUCOUS MEMBRANE. The normal mucoperiosteal lining of a paranasal sinus is less than 1 mm. thick. Fibrous thickening of the mucous membrane occurs as the result of chronic inflammatory disease and results in the widening of the soft tissue shadow just inside the bony walls of the involved sinus. When the inflammatory reaction producing this change is due to chronic infection, the inner surface of the thickened mucous membrane is smooth and regular (note maxillary sinuses in Plate 13, *C*). Allergic sinusitis, on the other hand, produces polypoid mucous membrane thickening accompanied by extensive polyp formation, literally packing the nasal passages, as shown in *D*. (Observe the wide differences in development of the frontal sinuses in the four patients shown in Plate 13.)

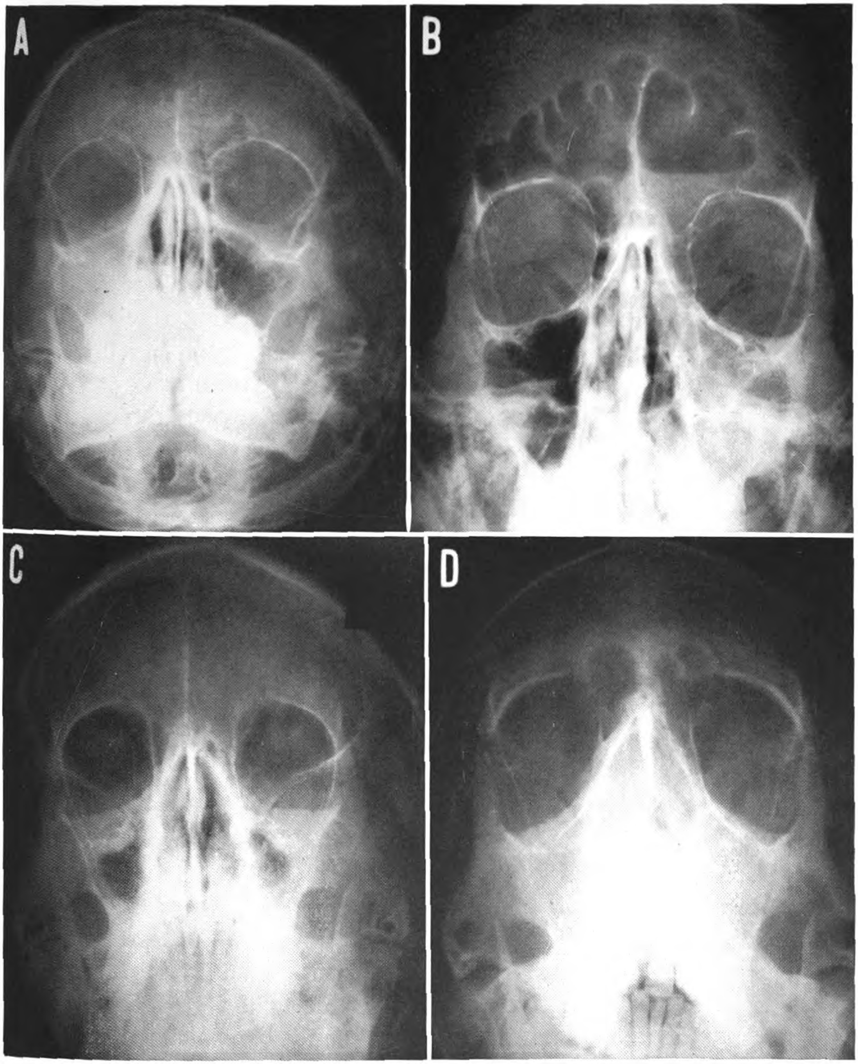


PLATE 13.—*A,* unilateral "clouding," maxillary antrum; bilateral clouding, frontal and ethmoid sinuses. *B,* patient upright; fluid in left frontal sinus and air-fluid level, and clouding of ethmoids and antrum on same side. *C,* greatly thickened mucous membrane lining of antra associated with chronic inflammatory disease. *D,* nasal passages and antra completely occluded by polyps associated with allergic sinusitis.

RETENTION CYST. Retention cysts incident to chronic inflammatory disease of nonallergic origin may develop in the mucous membrane lining of a sinus, usually one of the maxillary antra. These cysts, resulting from blockage of a mucous gland, appear as dome-shaped single or multiple opacities projecting into the sinus cavity (Plate 14; note left antrum in *A*). It is difficult to differentiate a retention cyst from a solitary polyp on the basis of roentgen findings alone.

MUCOCELE. This lesion, an accumulation of secretions within a sinus due to a chronically blocked ostium, may eventually expand and erode bone. It occurs most often in a frontal sinus, where it is likely to bulge into the adjacent orbit or even expose the dura. When such a lesion contains pus rather than mucous, it is called a pyocele.

REGIONAL OSTEITIS AND OSTEOMYELITIS. In the presence of chronic inflammatory sinus disease, recognizable alterations in adjacent bone sometimes occur. The sharply delineated walls of the involved air pockets become hazy, and surrounding bone shows increase in roentgenographic density. Such abnormality, seen most commonly around the frontal sinuses, denotes regional osteitis.

Plate 14, *B*, shows, in addition to marked clouding of the maxillary antra and moderate clouding of the frontal sinuses, well-defined frontal regional osteitis. Ordinarily this type of inflammatory reaction is not a dangerous lesion. On the contrary, the increased density of bone is an indication of chronicity and repair, suggesting that the patient's resistance is sufficient to prevent the infection from spreading wildly through the cranial bones, as happens in acute osteomyelitis. Fortunately, the latter condition is rare since the advent of antibiotic therapy.

NEOPLASM. Considering the great majority of polyps as products of inflammatory disease, the only benign neoplasms of the paranasal sinuses that need to be considered are osteomas and ossifying fibromas. The new bone produced by these relatively harmless tumors is densely calcified, appearing on roentgenograms as snow-white areas of increased density. A large osteoma located entirely within the right frontal sinus is shown in Plate 14, *C*. Such lesions are uncommon.

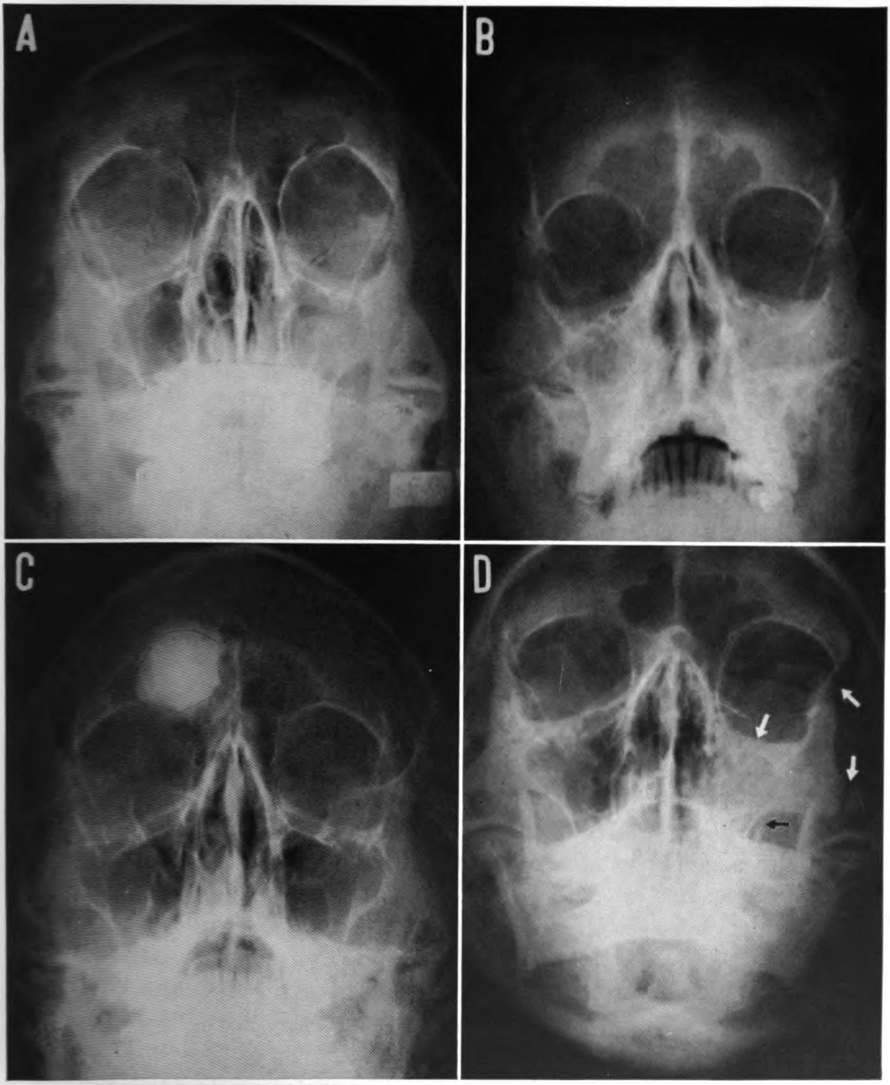


PLATE 14.—*A*, polypoid mass (mucocele or polyp) in left maxillary antrum. *B*, osteitis, represented by margins of increased bone density surrounding frontal sinuses; maxillary antra extensively clouded. *C*, dense shadow of benign osteoma in right frontal sinus. *D*, clouded left antrum with associated fractures; clouding was due to hemorrhage into the sinus.

Among the malignant tumors of the sinuses, sarcoma in children and carcinoma in adults are by far the most important. Both of these lesions characteristically produce early clouding of the involved sinus, followed later by expansion, invasion and eventual complete destruction of the sinus walls.

FRACTURES. Roentgen examination of the paranasal sinuses following severe facial trauma frequently yields evidence of fractures, which usually are multiple and at times are notoriously difficult to identify as to precise location. A commonly encountered combination of facial bone fractures consists of a depression of the infraorbital ridge, a break in the zygomatic arch and a separation of the zygomaticofrontal suture. In *D* (Plate 14) this combination of fractures is seen on the left side of the face. Note that there also is a fracture of the lateral wall of the clouded left antrum. In this instance the clouding is due to traumatic hemorrhage. Fractures of the nasal bones are common and are best shown by a special lateral projection of the head, underexposed to demonstrate the delicate osseous structure of the nasal bridge.

THE ORBITS

The roentgenologist often is called on to determine whether or not a foreign body is imbedded in the soft tissues of an orbit. Whereas tiny fragments of metal are opaque to x-rays and appear on properly exposed films as flecks of increased density, small particles of glass, wood, etc., are ordinarily not radiopaque and therefore cannot be detected roentgenographically. Special apparatus has been designed to permit extremely accurate localization of metallic intraocular foreign bodies by roentgen methods. Obviously, such procedures greatly facilitate the execution of the delicate operations required for removal of the foreign material.

The optic foramina are located on the posteromedial aspects of the orbits and cannot be seen on conventional sagittal projections of the skull. For adequate visualization of these foramina as well as of the medial walls of the orbits, it is necessary to use oblique projections of the skull somewhat similar to the Stenvers

position, but with the x-ray beam centered more medially. One application of this technic is the recognition of certain tumors which arise in the optic chiasm and infiltrate one or both optic nerves through the optic foramina. The resulting erosion and dilatation of the foramina are readily identified roentgenographically.

THE MASTOIDS

The mastoids are not independent osseous structures but are poorly defined divisions of the petrous portions of the temporal bones. It is important to remember that their development is an intricate process occurring almost exclusively after birth. In the early postnatal period only a single mastoid cell, the antrum, is present bilaterally. Beginning about the sixth month, the pneumatic cells which characterize the mastoids begin to form as the result of epithelial outpouchings from the antrum, the middle ear and the eustachian tube. With this epithelial hyperplasia there is concomitant dissolution of adjacent bone, and eventually the entire mastoid process becomes honeycombed with air-containing cells having thin, delicate walls. Additional cells may extend upward into the temporal squama, anteriorly into the zygoma, posteriorly over the sigmoid sinus and medially into the tip of the petrous bone. This process of pneumatization takes place largely between the ages of one and five and is completed in most instances at the age of puberty.

It should be emphasized that developmental variations in the mastoids are common, with every possible degree of limited pneumatization taking place. Those portions of the mastoids which do not become completely pneumatized have a partially aerated (diploic) structure or are densely sclerotic. Individual cells may be large, small or a mixture of both, and furthermore may be of all conceivable shapes. Chronic middle ear disease occurring during the formative period of the mastoids may not be responsible for all of the developmental irregularities observed, but it undoubtedly plays an important role in retarded or arrested pneumatization, in the relative thickness of individual cell walls and in the development of some instances of sclerosis.

These remarks concerning mastoid development are introduced because the student will find that his ability to diagnose mastoid disease from roentgenograms is directly proportional to his knowledge of the anatomic complexities of the temporal bone. He should not become discouraged by this realization, however, because relatively few physicians can boast complete mastery of both the anatomic and pathologic aspects of the temporal bone, the most highly complicated of osseous structures.

Close co-operation between the otolaryngologist and the roentgenologist is desirable if full advantage is to be taken of the valuable information which good-quality roentgenograms have to offer. In addition to detection of disease processes, x-ray films of the mastoids will reveal the type and extent of cellular development, the size and position of the sigmoid sinuses and the presence or absence of emissary veins. They will act as a guide during surgical drainage and will serve as a permanent record of the patient's disease. At the same time, the limitations of the roentgen method should be clearly appreciated, for x-ray findings notoriously lag behind clinical signs of mastoid disease, and the film gives no indication of the type of infecting organism, spread of infection or the patient's general condition.

Several different views of each mastoid are necessary for accurate evaluation of these structures (Plate 15). This is particularly true because of the high incidence of developmental variations already mentioned and because of the unique position of the mastoids in relation to surrounding structures. Similar exposures of both mastoids on the same film are helpful in that abnormal and normal sides may be compared simultaneously.

Law projection (Plate 15, *A*).—If one observes a routine lateral projection of the skull (Plate 18, *B*, p. 84), it will be seen that the shadows of the two mastoids overlap, and as a result adequate independent visualization of either is not pos-

---

PLATE 15.—*A:* Law projection. *1,* temporomandibular joint; *2,* auditory canal; *3,* sigmoid plate; *4,* sigmoid sinus; *5,* mastoid cells. *B:* Stenvers projection. *1,* tegmen tympani; *2,* internal auditory canal; *3,* petrous apex; *4,* mastoid antrum; *5,* periantral mastoid cells; *6,* mastoid tip. *C:* Occipital projection. *1,* petrous ridge; *2,* internal auditory canal; *3,* mastoid antrum; *4,* mastoid cells; *5,* foramen magnum. →

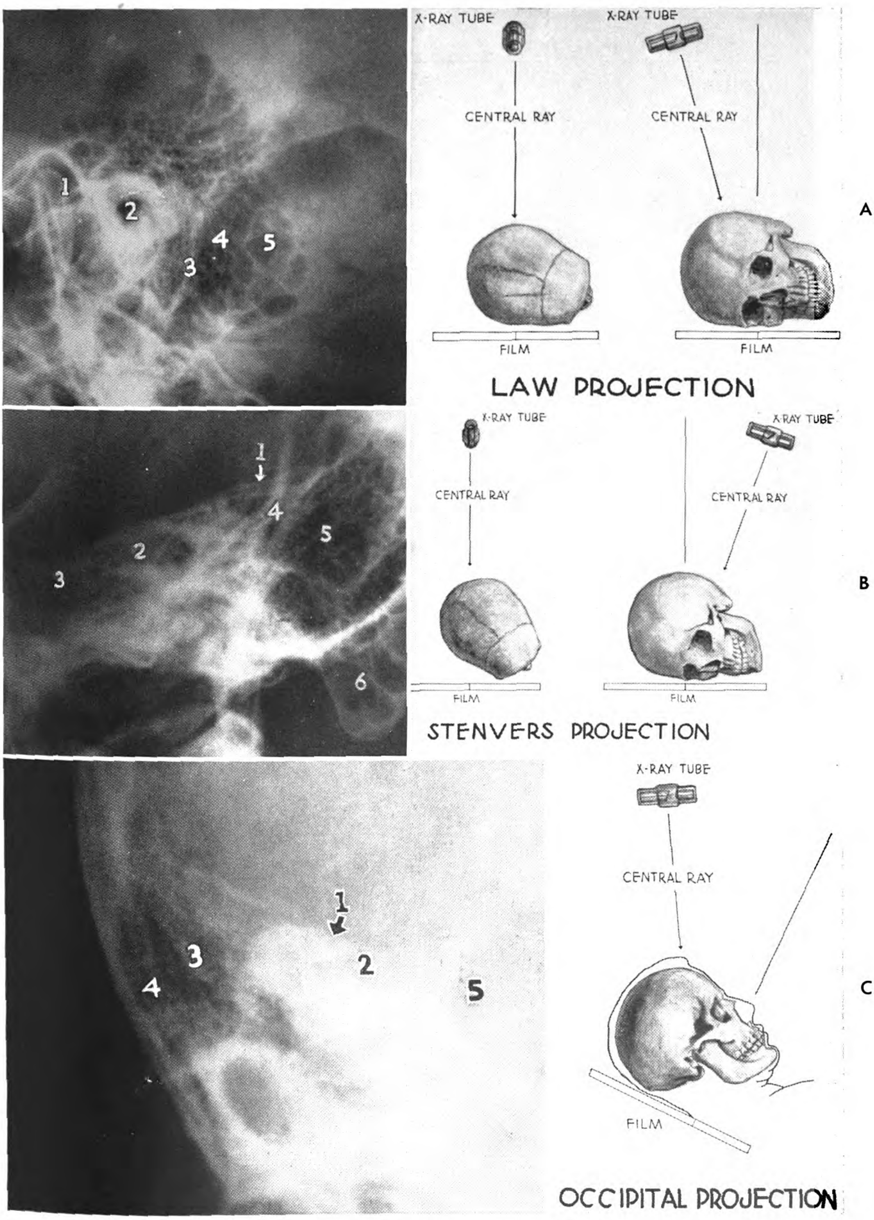

X-RAY TUBE
X-RAY TUBE
CENTRAL RAY
CENTRAL RAY
FILM
FILM
A
LAW PROJECTION
X-RAY TUBE
X-RAY TUBE
CENTRAL RAY
CENTRAL RAY
FILM
FILM
B
STENVERS PROJECTION
X-RAY TUBE
CENTRAL RAY
FILM
C
OCCIPITAL PROJECTION

PLATE 15

sible. To overcome this difficulty, the positions of the x-ray tube and the patient's head are shifted to form the composite angle shown in the diagram in Plate 15, *A*, so that a modified lateral view of the mastoid on the side closest to the film is obtained.

Stenvers projection (*B*).—This is another composite-angle projection which gives an oblique, postero-anterior view. The petrous portion nearest the film is seen to good advantage.

Occipital projection (*C*).—This view represents the closest practicable approach to a true anteroposterior projection of the mastoids. With the patient's occiput next to the film, the x-ray tube is angled toward the feet. Although only the right mastoid is shown here, a view of both sides is conveniently obtained with a single exposure.

It is our opinion that for student consumption the basic abnormalities of the mastoids are best presented under the headings of objective findings which can actually be observed on the roentgenograms just described.

CLOUDING. The fundamental roentgenologic change occurring in conjunction with inflammatory disease of a well-pneumatized mastoid is alteration in the density of normally radiolucent air cells. In the early stages of acute mastoiditis, the diffuse haziness of mastoid cells which appears is commonly referred to as "clouding." Clouding does not necessarily indicate mastoid infection per se, because the inevitable mucosal edema of the mastoid incident to simple otitis media produces exactly the same appearance. In actual mastoid infection, progress of the disease manifests itself as increased clouding and diminution in the normally sharp outline of individual cell walls. (Observe right mastoid in Plate 16, *A*.)

BONE DESTRUCTION. Eventually the delicate bony septa of the mastoid cells are destroyed by inflammatory granulations plus the pressure of accumulated pus, the small cells coalescing to form a sizable cavity which in effect is a mastoid

PLATE 16.—*A*, "clouding" of right mastoid; left mastoid normal. *B*, bilateral mastoid sclerosis (note defect in left mastoid from cholesteatoma). *C*, sclerotic mastoid (right) with large cholesteatoma. →

→ Normal mastoid cells

→ cloudy mastoid

→ Sclerosis

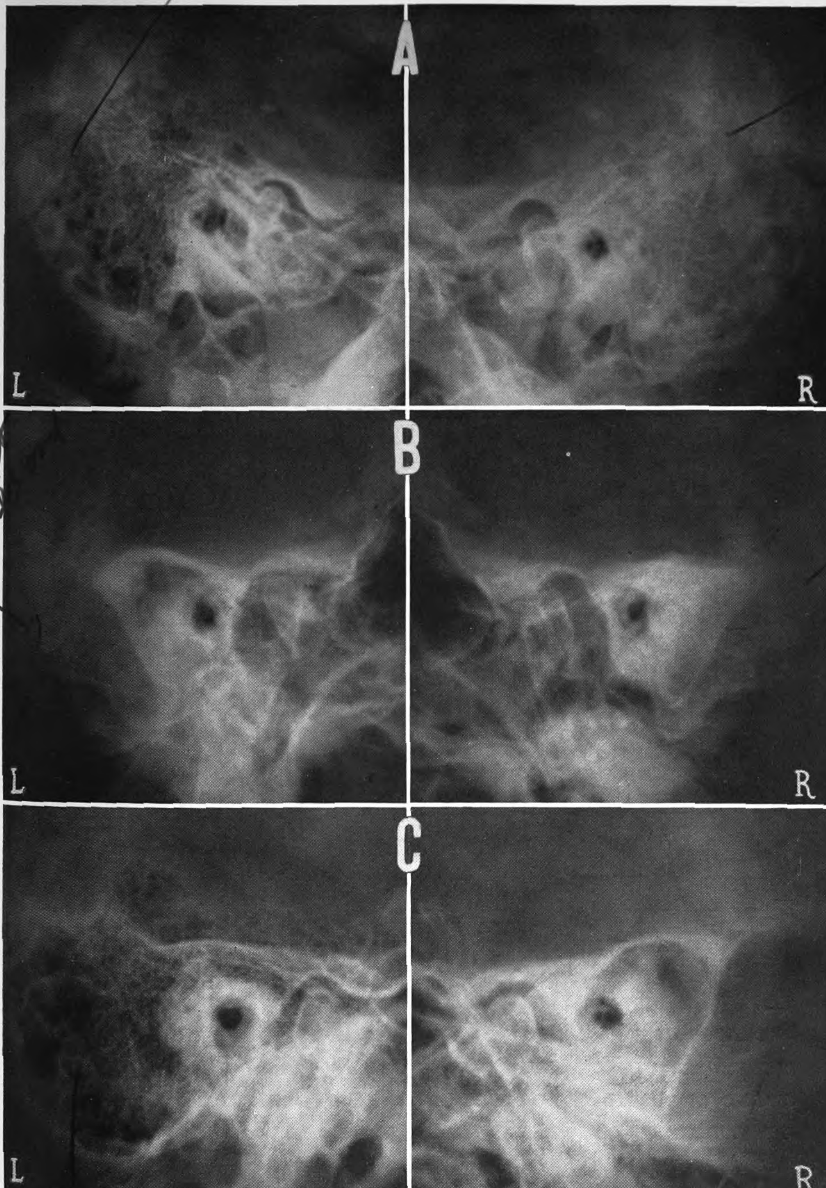


PLATE 16

normal mastoid

circumscribed area of increased density due to cholesterol deposition

abscess. These abscesses usually are recognizable on roentgenograms as areas of decreased density, but at times they cannot be distinguished from large normal cells. Careful evaluation of the over-all cellular structure of both mastoids may be helpful in making this differentiation.

THICKENING OF CELL WALLS. Acute mastoiditis occasionally regresses spontaneously, leaving no residual roentgenographic signs of disease. On the other hand, a severe acute infection which eventually subsides, repeated exacerbations of chronic inflammatory disease or a persistent, smoldering, infectious process usually shows signs of bone repair in the form of thickened cell walls. These thickened septa can be recognized on the film because of their increased calcium content.

SCLEROSIS. One frequently encounters roentgenograms of mastoids in which there is little or no cellular development and in which the osseous structure appears compact and ivory white (Plate 16, *B*). This extreme deviation from the pneumatic type of mastoid is commonly considered the result of local infection during the time the mastoid cells normally develop, namely, the first five or six years of life. It seems probable, however, that a long-standing infection beginning after the mastoid is completely developed may result in a similar change. In either case, the inference to previous infection is contained in the diagnosis of chronic sclerotic mastoiditis, popularly used to denote such abnormality.

The importance of roentgen diagnosis in the proper management of mastoid disease is especially evident when one considers the possibility of an acute infection in a "chronic sclerotic mastoid." In the normal pneumatic mastoid, infection spreads slowly through the delicate cell walls, individual cells acting as "pockets of resistance" fighting a delaying action against the onslaughts of virulent, invasive bacteria. This gives the surgeon ample opportunity to temporize if he thinks the infection can be controlled by conservative measures. In the case of the acellular mastoid, the path of least resistance for an acute infection is directly through the roof of the mastoid into the meninges and brain, thus making immediate surgical drainage imperative

if dangerous intracranial complications are to be avoided. It is evident, then, that careful preoperative roentgenographic appraisal of mastoid structure may actually be the determining factor in instituting surgical drainage.

CHOLESTEATOMA. In chronic mastoiditis with associated perforation of the tympanic membrane, epidermis from the external ear may spread into the middle ear and mastoid via the antrum. Desquamation of the epidermis continues inside the mastoid, and cholesterol is deposited within the epithelial debris. This collection of foreign material, which is known as a cholesteatoma, becomes progressively larger and slowly invades adjacent bone. Roentgenologically, cholesteatomas are seen in or near the antrum as well-circumscribed areas of decreased density bounded by ringlike zones of sclerotic bone. (Plate 16 shows a large cholesteatoma involving the right mastoid in *C*. Note also the smaller cholesteatoma in the left mastoid in *B*.)

NEOPLASM. Neoplastic invasion of the mastoid produces destructive changes usually indistinguishable from those caused by inflammatory disease, the same is true of the reticuloendothelioses such as Schüller-Christian disease and Letterer-Siwe disease, which occasionally present their earliest manifestations of bone involvement in the mastoid (Plate 24, *E*, p. 99).

OPERATIVE DEFECTS. Radical mastoidectomy defects can readily be identified on roentgenograms, but "man-made" cavities resulting from incomplete exenteration of mastoid cells are sometimes difficult to distinguish from pathologic areas of bone destruction. This fact again emphasizes the fallacy of basing diagnosis solely on the roentgenologic findings.

THE MANDIBLE

Special oblique projections are required to examine the mandible roentgenographically because of its unique shape and the presence of numerous overlapping shadows cast by neighboring structures. To satisfy the time-honored roentgenologic rule that bones be examined in two different planes, three separate views of the mandible are required—a lateral oblique projec-

tion of each side on separate films and an anteroposterior projection of both sides on a single film.

The awkward head positions required of the patient undergoing examination of the mandible are difficult for the average person to assume, and consistently good technical results are not always possible. Nevertheless, every effort should be expended toward this end because of the valuable diagnostic information which can be obtained from good-quality roentgenograms.

FRACTURES. The horseshoe shape of the mandible adds considerably to its inherent strength; but, because of its vulnerable position, this bone is very commonly fractured. Multiple, simple, complete breaks are the rule, and the commonest sites of involvement are the angles at the junction of the horizontal and vertical rami, the canine regions and the necks of the condyles. Plate 17, *A*, illustrates a fracture at the angle of the mandible on the right side with slight displacement of fragments. In viewing a lateral projection of the mandible, one must be careful not to mistake for a fracture the linear air shadow between the base of the tongue and the soft palate.

Delayed union is relatively common, but in the mandible the roentgenogram is not a reliable gauge of this complication. Roentgen evidence of a well-defined fracture line may persist for months after definite clinical signs of solid union are evident. So-called "pathologic" fractures are not uncommon with underlying disease such as osteomyelitis, cyst formation or neoplasm.

Anterior dislocation at the temporomandibular joints, when present, is readily shown by the Law projection described in conjunction with the mastoids (Plate 15, *A*). Care must be taken not to confuse true dislocation of the condyles with the normal anterior excursion of these structures.

OSTEOMYELITIS. Nonspecific osteomyelitis of the mandible is usually the result of direct extension of an adjacent infectious process, usually an abscessed tooth. The destructive phase of the disease is similar to that observed in hematogenous osteomyelitis of the long bones. Early regional decalcification is followed by patchy bone destruction and the formation of multiple sequestra which persist for long periods. The reparative phase

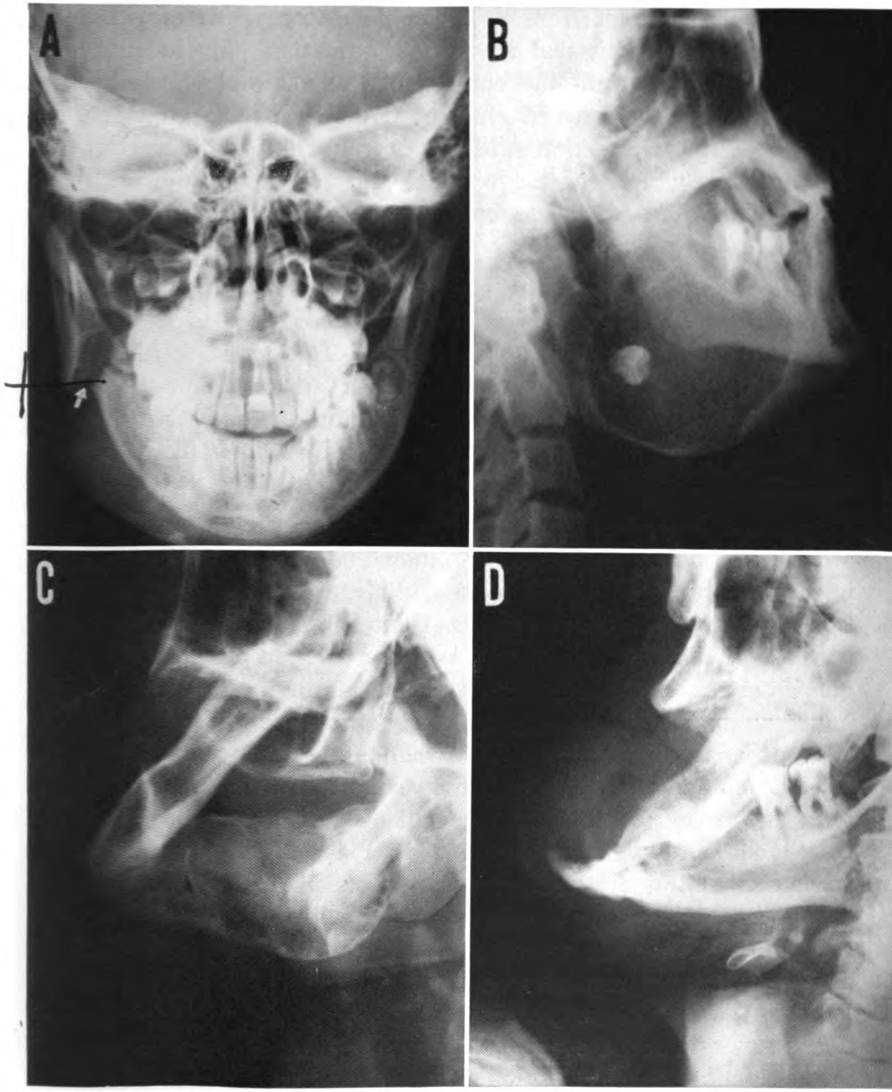


PLATE 17.—*A*, fracture at angle of the right mandible. *B*, large dentigerous cyst, left, with included tooth. *C*, deformity and altered texture of horizontal ramus, right mandible, produced by circumscribed ossifying fibroma. *D*, distinctive invasion of mandible by extension of a carcinoma arising in the floor of the mouth.

is somewhat different from that seen in osteomyelitis of other bones. Little subperiosteal new bone formation (involucrum) occurs, and as a result the contour of the mandible is nearly normal despite the marked changes in the trabecular pattern. When and if the infection subsides, it frequently resolves completely, leaving none of the residual scars or deformities classically associated with osteomyelitic involvement of the extremities.

SPECIFIC INFECTIONS. Of the specific granulomas, only actinomycosis occurs with sufficient frequency to deserve the attention of the student of medicine. This lesion is almost invariably due to direct extension of an adjacent soft tissue lesion. The bone destruction which it produces is indistinguishable roentgenographically from that caused by nonspecific osteomyelitis.

BENIGN CYSTS AND NEOPLASMS. Cystic tumors arising from dental epithelium (epithelial odontomas) commonly involve sizable portions of the mandible, and three particular types warrant a brief description. Dental root cysts develop in association with periapical tooth infection and are seen on roentgenograms as well-circumscribed zones of radiolucency producing some degree of expansion of surrounding bone. Dentigerous cysts differ in appearance only in that they contain partially or fully developed teeth. Adamantinomas are also cystic in appearance but usually contain fine trabeculae which divide the cystic cavity into multiple compartments. In Plate 17, *B,* is shown a large dentigerous cyst involving the left side of the mandible; within the cyst is a fully developed tooth.

Giant cell tumors, traumatic hemorrhagic bone cysts and ossifying fibromas are other benign lesions sometimes encountered in the lower jaw. Observe in Plate 17, *C,* the well-circumscribed margin and the peculiar pattern of the ossifying fibroma in the right horizontal mandibular ramus.

MALIGNANT NEOPLASMS. Osteogenic sarcoma occasionally arises in the mandible, but all primary malignant bone neoplasms are rare in this location. On the other hand, direct extension into the mandible of a carcinoma arising in the alveo-

lar ridge, the tongue, the floor of the mouth or the cheek is a relatively common occurrence. Note in Plate 17, *D*, that the anterior portion of the mandible has been invaded and partially destroyed by carcinoma arising in the floor of the mouth. The line of demarcation between normal and diseased bone is poorly defined. Radiologic evidence of metastatic bone involvement is of considerable value, for it usually alters both the prognosis and the method of treatment of the primary neoplasm. Metastatic carcinoma of the mandible presents a roentgenologic appearance similar to that observed in osteomyelitis of this bone; in fact, the two lesions frequently coexist. Radiation necrosis, shown in Plate 95 (p. 345), may be indistinguishable from either.

THE SALIVARY GLANDS

Salivary gland calculi, which are much commoner in the submandibular glands than in the parotids, may be identified on plain films if they contain sufficient calcium salts to be radiopaque. Since some of these stones (20 per cent) are nonopaque, their presence must be determined by the use of *sialography*, the injection of an opaque contrast medium into the duct system of a salivary gland. Sialograms also are useful in the diagnosis of other salivary gland abnormalities, such as strictures, inflammatory lesions and neoplasms.

THE CRANIAL VAULT

Whereas the bones making up the base (floor) of the skull are preformed in cartilage, those that eventually unite to form the cranial vault are largely the products of membranous bone development. At birth, ossification of this membranous bone is so incomplete that, in the normal living infant, the broad sutures and fontanels between the bones make up as much as one-fourth the total surface of the calvarium (Plate 18, *A*). Often the extremely thin, flat bones of the vault are difficult to differentiate roentgenologically from surrounding soft tissues, giving the impression that even less bone is present than is actually the case. Another outstanding feature of the newborn skull is

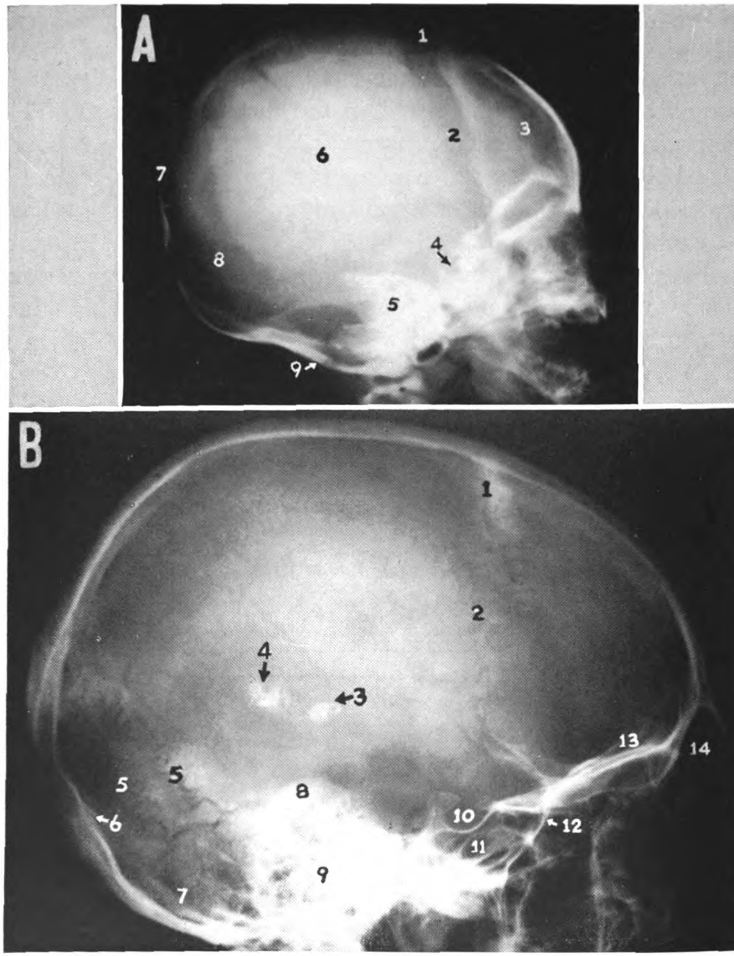


PLATE 18.—*A:* Lateral projection of infant's skull. *1,* anterior fontanel; *2,* coronal suture; *3,* frontal bone; *4,* sella turcica; *5,* superimposed infantile mastoids; *6,* parietal bone; *7,* posterior fontanel; *8,* lambdoidal suture; *9,* occipital bone.

B: Lateral projection of adult's skull. *1,* partially ossified coronal suture; *2,* middle meningeal artery groove; *3,* calcified pineal gland; *4,* overlapping calcified choroid plexuses; *5,* lambdoidal suture; *6,* internal occipital protuberance; *7,* posterior fossa; *8,* helix of ear; *9,* overlapping mastoids; *10,* sella turcica; *11,* overlapping sphenoid sinuses; *12,* anterior border of middle fossa; *13,* anterior fossa; *14,* overlapping frontal sinuses.

the large size of the calvarium in relation to the base and the face bones.

Ossification of the skull progresses rapidly in the immediate postnatal period, the small posterior fontanel closing at six weeks and the large anterior fontanel disappearing at eighteen months. At two years of age most of the roentgenographic characteristics of the adult skull are present. One notable exception, however, is that up to the age of three or four the skull bones may appear on the roentgenogram as a single layer. Beyond this age period, the apparent single thickness of the vault gradually resolves into three distinct layers—the compact inner and outer tables and the intervening cancellous diploe.

In regard to the technic of skull examination, it has been found advisable to make seven exposures in three different projections. Right and left lateral views and a postero-anterior view are prepared in stereoscopic pairs; a single exposure in the occipital (anteroposterior) projection usually suffices.

Lateral projection of the normal skull.—When viewed stereoscopically, a lateral roentgenogram of the skull (Plate 18, *B*) gives one the impression of looking at a sagittal anatomic hemisection of this structure with the added advantage of being able to see inside the different layers of bone. It is important for the observer to survey with care the thickness, texture and contour of the skull bones in an orderly fashion and to discount numerous normal markings which may simulate disease. Since it is impossible in a limited treatise such as this to cover all of these normal variations in a comprehensive manner, only the most constant and therefore the most important ones will be mentioned.

Localized thinning of the temporal squama is invariably seen, appearing as an area of decreased density corresponding to the anatomic position of this bone bilaterally. Additional normal areas of lessened density frequently are found in the inferior occipital and inferior frontal regions.

Convolutional (digital) markings are highly variable zones of decreased density on the inner table of the skull corresponding in size and direction to the gyri of the brain. They are especially common in children between the ages of six and

fifteen and apparently represent nothing more than normal pressure of the growing brain on the inside of the cranium.

Cranial sutures in the adult skull are visible as fine, serrated, linear markings whose saw-toothed appearance and anatomic location serve to distinguish them from fracture lines. One should become familiar with the roentgen appearance of the coronal suture separating the frontal and parietal bones, the lambdoidal suture between the parietal and occipital bones and the sagittal suture which divides the two parietal bones. With the exception of the frontal suture, which normally is obliterated by the fifth year in 90 per cent of all persons, none of the cranial sutures begins to fuse prior to cessation of all skeletal growth. Progressive ossification of the margins of the sutures then produces characteristic bands of increased density which must not be mistaken for abnormal intracranial calcification. Incidentally, tiny, anomalous centers of ossification within the sutures or fontanels commonly give rise to single or multiple ossicles called wormian bones.

Venous lakes, representing localized dilatations of the cerebral veins as they enter the longitudinal venous sinus, and arachnoid granulations, through which the cerebrospinal fluid is absorbed, normally produce round or irregular areas of thinning of the skull along the sagittal suture. Roentgenographically, these normal markings show up as small, dark holes on either side of the suture in the region of the vertex.

Middle-meningeal arterial grooves are rather consistent findings on skull roentgenograms of adults. They are seen as linear shadows of decreased density just posterior to the coronal suture. Prominent diploic veins producing a similar appearance occasionally parallel these arterial grooves.

The floor of the skull as viewed in lateral projection may be conveniently divided into the anterior fossa, the middle fossa and the posterior fossa. Within the middle fossa is the sella turcica, probably the most important single structure in the skull from the standpoint of roentgenologic detection of intracranial tumors. The anterior wall of the sella turcica terminates

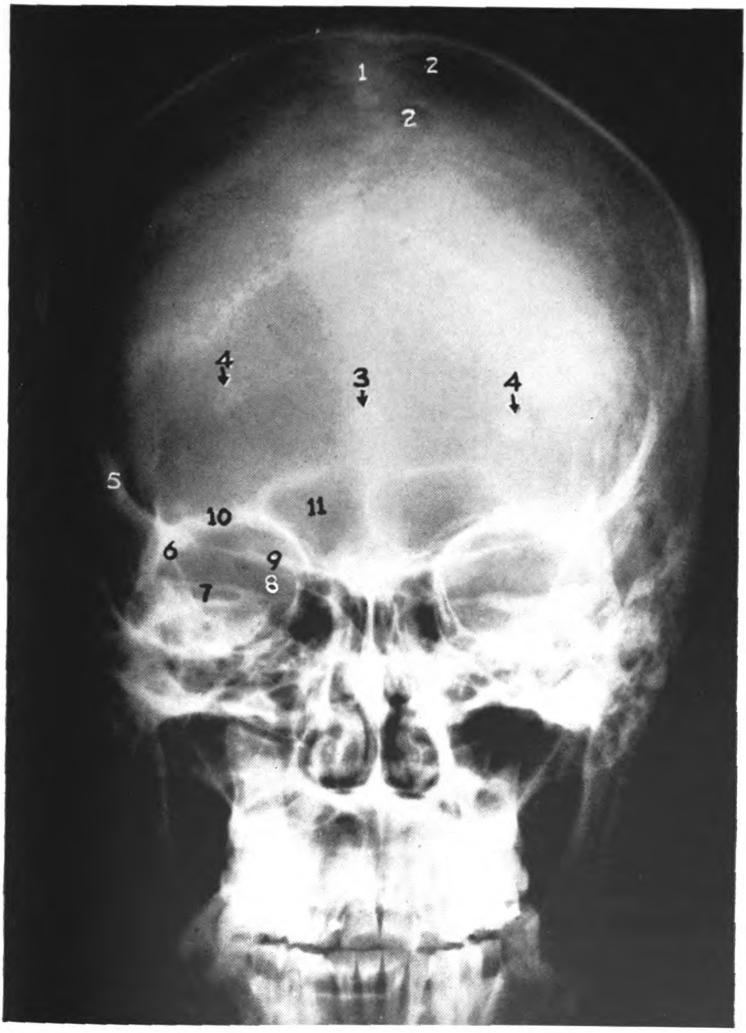


PLATE 19.—Postero-anterior projection of adult's skull. *1,* sagittal suture; *2,* arachnoid granulations; *3,* calcified pineal gland; *4,* calcified choroid plexus; *5,* sphenoid ridge; *6,* cross-section of greater wing of sphenoid; *7,* petrous ridge; *8,* superior orbital fissure; *9,* lesser wing of sphenoid; *10,* orbital roof; *11,* frontal sinus.

in the tuberculum sellae, from which two short, rather blunt, osseous projections known as the anterior clinoid processes are directed posterolaterally. The posterior border of the sella (dorsum sellae) terminates superiorly in two posterior clinoid processes.

Postero-anterior projection of normal skull.—This view, which is similar to the Caldwell projection of the paranasal sinuses, permits visualization of the head in a plane at direct angles to the lateral projection and serves the valuable purpose of determining bilateral symmetry of many cranial and intracranial shadows.

In a properly exposed postero-anterior roentgenogram of the skull (Plate 19), one sees a shadow of bone extending horizontally across each orbit in such a manner that the lower half of the orbit is much denser than the upper half. The shadow of increased density represents the petrous portion of the temporal bone and its upper margin is commonly spoken of roentgenologically as the petrous ridge. A less prominent ridge of bone projects through the upper portion of each orbit and extends beyond its lateral wall in an upward and outward curvilinear fashion. This shadow is the sphenoid ridge, being made up of a portion of the lesser sphenoid wing and the orbital process of the frontal bone. Still another shadow of increased density may be recognized within the circle of each orbit, extending almost vertically and appearing to connect the petrous and sphenoid ridges. This ridge of bone is nothing more than a cross-section of the greater wing of the sphenoid bone. In addition to the three osseous ridges just described, the observer should routinely identify the superior orbital fissure, a triangular slitlike shadow of decreased density projected on the medial aspect of the orbit.

Anteroposterior (occipital) projection of normal skull.—Mention has been made of this particular view in conjunction with routine mastoid examination. As a part of the routine skull survey, it is used primarily to show the posterior fossa and the occiput. The lambdoidal suture, the foramen magnum, the cruciate ridge, the occipital protuberance and the lateral venous sinus grooves are some of the prominent landmarks which may be observed in this projection (Plate 20).

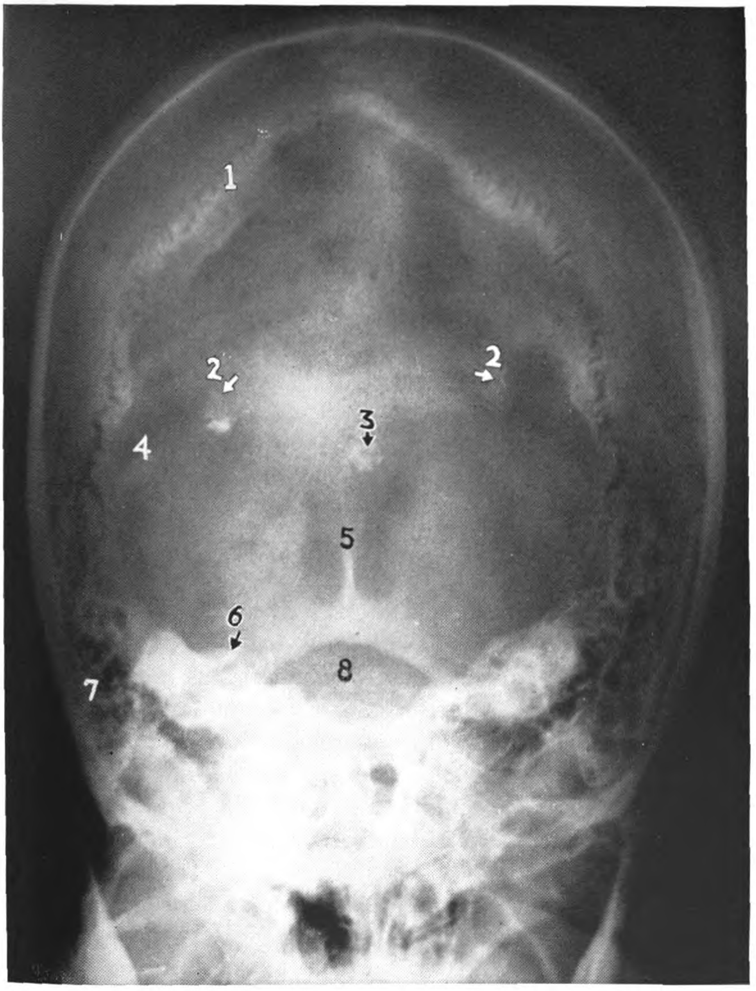


PLATE 20.—Occipital projection of adult's skull. *1,* lambdoidal suture; *2,* calcified choroid plexus; *3,* calcified pineal gland; *4,* groove for transverse sinus; *5,* crucial ridge; *6,* petrous ridge; *7,* mastoid; *8,* foramen magnum.

PHYSIOLOGIC CALCIFICATION. Although the normal brain tissues cannot be identified on plain skull roentgenograms, so-called physiologic calcification may occur in various portions of the brain or meninges and readily be seen on any or all of the routine skull exposures as localized areas of increased density. This "normal" intracranial calcium deposition is classed as physiologic because it has no known clinical importance. The following sites of physiologic calcification are briefly described in the order of their relative frequency of occurrence.

The pineal gland is calcified in 60 per cent of all individuals over twenty. In lateral projections it is located at a point approximately 3 cm. behind and a similar distance above the dorsum sellae. Sagittal projections show it to be directly in the midline. The calcium deposit seldom measures more than 4 mm. in diameter (Plates 18, *B*, 19 and 20).

The falx cerebri, which extends as a vertical septum between the cerebral hemispheres, occasionally contains one or two small, homogeneous plaques of calcium best seen in postero-anterior or occipital projections (arrow, Plate 25, *F*, p. 103).

The glomus of the choroid plexus in each lateral ventricle may contain stippled lime-salt deposition, the appearance of which is usually characteristic. In a true lateral projection of the skull these calcium deposits present small, round, superimposed shadows of increased density measuring from 0.5 to 1 cm. in diameter and located just behind and slightly above the pineal region (Plates 18, *B*, 19 and 20).

Physiologic calcification may also be observed at times in the diaphragma sellae, the anterior attachments of the tentorium cerebelli (petroclinoid ligaments), the walls of the superior longitudinal sinus and the basal ganglia.

SIGNIFICANT ANOMALIES OF CRANIAL BONES. Complete failure of development of the skull bones and brain results in the rare anencephalic monster, the roentgenologic diagnosis of which can usually be made in utero. Partial failure of development of the cranial bones is exemplified by midline defects associated with protrusion of portions of the meninges

and brain. These meningoencephaloceles are most commonly found in the frontal and occipital regions. In addition to the defect through which brain herniation takes place, the remainder of the skull in these patients commonly has a peculiar soap-bubble appearance known as *Lückenschädel.*

Craniosynostosis is premature fusion of the cranial sutures before the brain is completely developed. Under such conditions, the expanding brain erodes the inner table of the rigid vault in which it is encased, producing accentuation of the convolutional markings and pronounced distortion of the base of the skull. Asymmetry of the vault develops, the ultimate shape depending on which sutures fuse prematurely. When the coronal, lambdoidal and sagittal sutures are all involved, anteroposterior and lateral expansion of the brain is restricted but is partially compensated for by increased expansion in a vertical direction. This produces a head with a high, peaked crown, oxycephaly (Plate 21, *A*).

The generalized skeletal dystrophies which follow are not rare if considered collectively, and frequently their roentgenologic skull changes are quite typical. The student and the non-specialist, however, should regard these entities in the light of their individual rarity and be content merely to have them brought to the attention as fascinating oddities in which roentgen diagnosis is useful. Achondroplasia, sometimes called chondrodystrophia foetalis, denotes the well-known dwarf with a normal-sized trunk and short, broad extremities. The base of the skull of this mentally competent dwarf is small, due to premature closure of the spheno-occipital suture. In compensation, the cranial vault is enlarged and the face bones seem disproportionately small. (Note in Plate 21 the striking contrast between the shape of the achondroplasic skull, *B,* and oxycephalic skull, *A.*) Dysostosis multiplex is an atypical form of achondroplastic dwarfism associated with lipoid disturbance, mental retardation, corneal clouding, hepatomegaly and splenomegaly. The skull is characteristically scaphocephalic (long and narrow), the sella turcica is elongated and there are signs of increased intracranial pressure, the cause of which is unknown. These skull changes

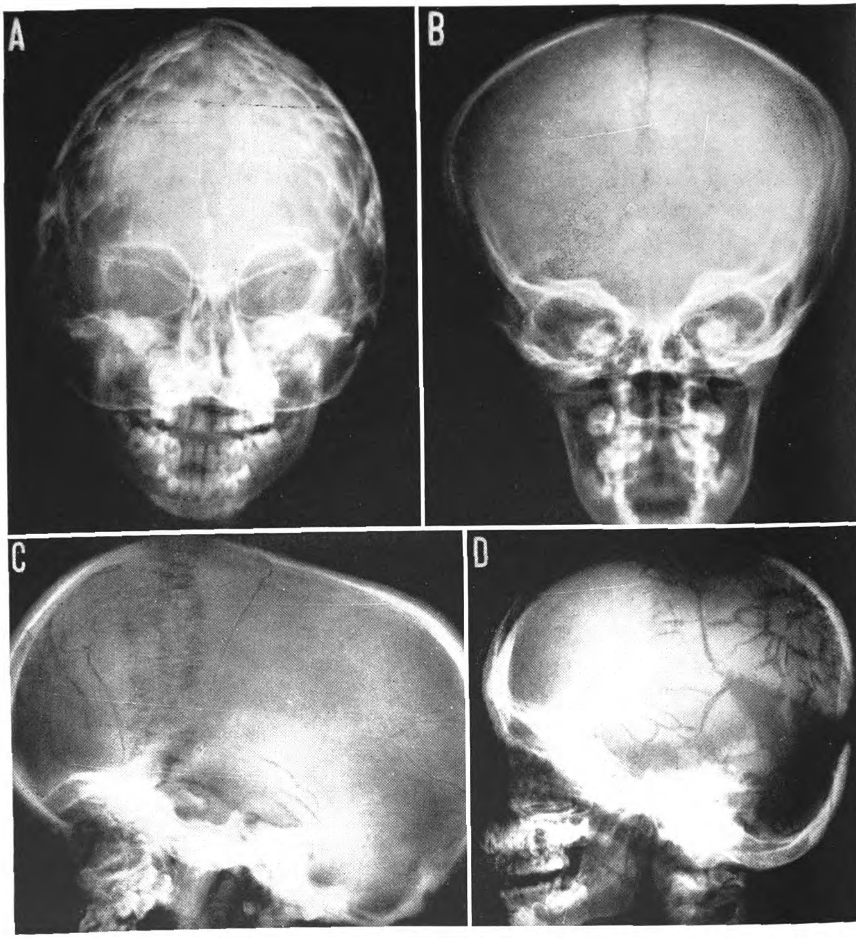


PLATE 21.—*A*, craniosynostosis. *B*, achondroplasia. *C*, dysostosis multiplex. *D*, dysostosis cleidocranialis.

are shown in Plate 21, *C*. Dysostosis cleidocranialis (*D*) is a hereditary syndrome characterized by a constant type of defective ossification in the skull and clavicles and less constant defects in other bones. The flat bones of the cranium show a spectacular prenatal pattern of incomplete ossification which may persist to some degree into adult life. Osteogenesis imperfecta also

produces delayed development of membranous skull bones resulting in a mosaic pattern that resembles, but does not represent, multiple fractures. The resemblance to fractures is emphasized because numerous fractures of osteoporotic vertebrae and long bones incident to minor trauma characterize this disease. Osteopetrosis results in uniform increase in density of all skeletal structures, producing a roentgenographic picture which is spectacularly diagnostic. The bones appear to be as hard as ivory but actually are quite brittle.

TRAUMATIC LESIONS OF THE CRANIUM. Fetal cephalhematoma is a relatively common manifestation of trauma during childbirth. Extravasation of blood beneath the periosteum of the skull produces a soft tumor which, if located near a fontanel, pulsates and simulates a meningocele. Roentgenograms made in the immediate postnatal period show a moundlike shadow of soft tissue density, usually in the parietal region. Absence of an associated defect in the skull serves to differentiate the hematoma from a meningocele. Several weeks after birth the hematoma will be surrounded by new bone laid down by the elevated periosteum (Plate 22, *A*).

Subdural hematoma, occurring in infancy, may produce signs of increased intracranial pressure. Old, untreated, organized hematomas of the subdural variety sometimes lead to localized thinning and deformity of the cranium.

Roentgen examination of the skull following head injuries is of importance in the recognition and localization of fractures in the cranial vault. Basilar fractures, however, frequently cannot be detected roentgenographically, and the possibility of a fracture in this region should never be dismissed on the basis of a negative x-ray report. The high degree of accuracy achieved by the roentgen method in the identification of cranial vault fractures has resulted in a demand for roentgenographic proof of such lesions in medicolegal disputes. Because this fact has been widely publicized, there is an unfortunate tendency among physicians to refer a patient for routine skull films the moment a cranial fracture is suspected, regardless of the presence of additional fractures, serious soft tissue injuries and generalized shock.

From the standpoint of the patient's immediate welfare, it is often wiser to postpone the examination until all vestiges of shock have disappeared.

Skull fractures may be classified as linear, comminuted or stellate, depressed and compound. The common linear fracture appears on the roentgenograms as a fairly straight, sharply defined line of diminished density, one end of which becomes narrower and terminates in a sharp point (note left parietal region in Plate 22, *B*).

A linear fracture must be differentiated from a suture line, an arterial groove on the inner table of the skull and a venous channel in the diploe. Suture lines are markedly irregular (serrated) and have a constant anatomic arrangement which fractures seldom simulate. Vessel markings have less well-defined margins, are usually branched and follow a fairly typical anatomic distribution. It is well to observe carefully the relationship of a fracture to visible vascular channels because this may permit early clinical recognition of epidural hemorrhage.

A comminuted fracture of the cranial vault is fairly common. It is ordinarily the result of direct violence and is frequently associated with serious underlying cerebral damage. Roentgenologically these fractures are apt to assume a stellate configuration with multiple linear shadows of increased density radiating from the point of injury (Plate 23, *B*).

A depressed fracture indicates some degree of inward displacement of at least one fragment of bone. The depressed fragment or fragments vary considerably in size, shape and extent of displacement. In this regard it is well to remember that even a few millimeters' depression is sufficient to cause significant pressure on the brain, and early surgical elevation of the displaced bone is desirable in nearly every case. For this reason some surgeons advocate immediate roentgen examination of the skull when depression of bone is suspected, regardless of the general condition of the patient. To determine the degree of depression present, one may use stereoroentgenograms and a tangential view made perpendicular to the site of injury. A projection made in the direction of the force producing the fracture may show confirmatory evidence of depression in an indirect

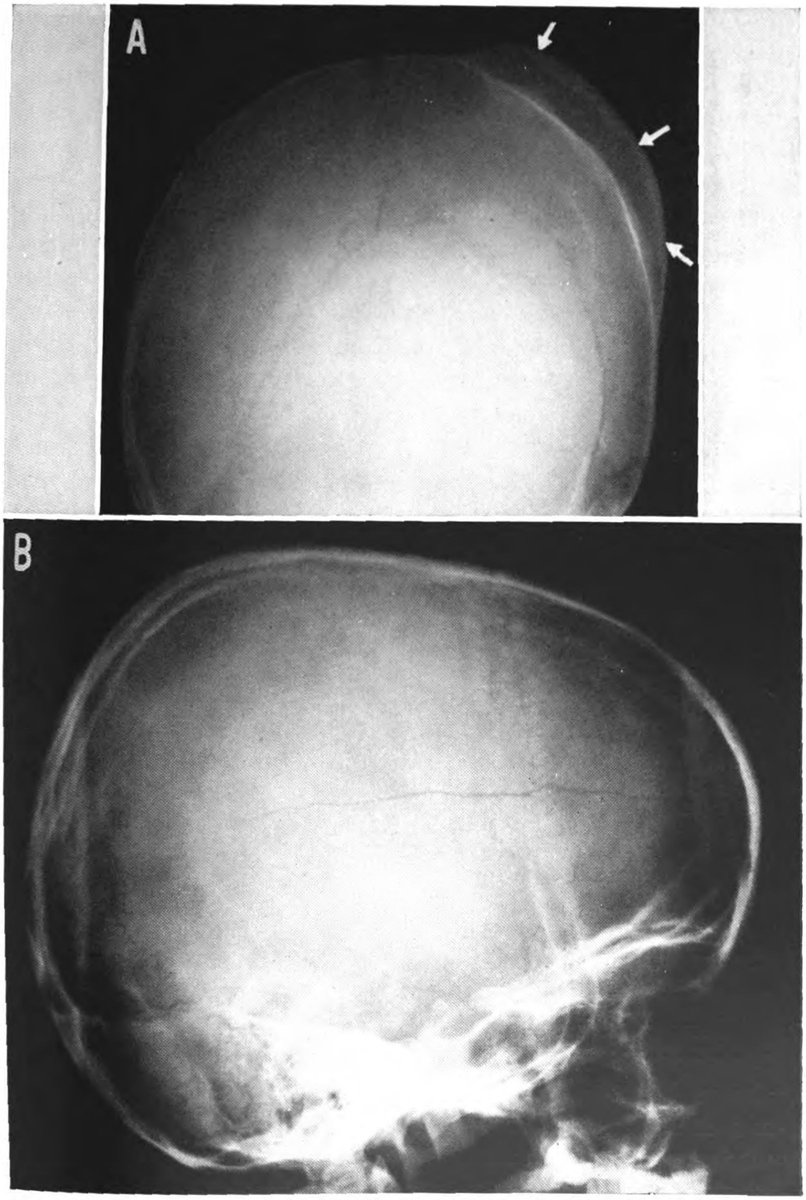


PLATE 22.—*A*, cephalhematoma. *B*, linear skull fracture.

manner. In this view, overlapping of the displaced fragment and the adjacent unaffected bone will produce a shadow of increased density of varying width. Plate 23, *A* and *B*, illustrates a comminuted, depressed fracture of the left parietal and occipital bones with most of the features just described.

A compound skull fracture implies communication between the site of fracture and the external surface of the scalp. Such fractures can be diagnosed roentgenologically by identification of air within the cranial cavity (intracranial aerocele) or by the presence of a foreign body, such as a bullet, inside the cranium. Incidentally, the course of a lead bullet usually can be followed through the skull and brain by observing the distribution of tracer substance (small particles of lead and bone).

Skull fractures that are healing present an appearance somewhat different from fresh ones. The characteristic, sharply defined margins of a recent fracture are gradually lost, and differentiation from vascular markings becomes progressively more difficult. Complete healing may be slow and residual roentgenologic signs may persist for months or even years.

INFLAMMATORY LESIONS OF THE CRANIUM. Osteomyelitis of the skull in infancy is almost invariably due to congenital syphilis and usually occurs in conjunction with syphilitic lesions in the long bones. The earliest roentgenologic signs of this disease are multiple mottled areas of decalcification; patchy bone destruction follows. The healing stages are characterized by new bone formation manifesting its presence in three ways. First, there is gradual sclerosis of the margins of the destructive lesions; second, there is decrease in the size of the destructive areas and, finally, there is complete restoration of normal bone structure.

Osteomyelitis of the skull in older children and adults usually is nonspecific in type and, as mentioned previously, is almost always due to extension from infections of the paranasal sinuses and mastoids. The acute form of the disease is one of overwhelming bone destruction, which formerly necessitated early surgical removal of large portions of diseased bone. As is true with many infectious processes, however, antibiotic therapy

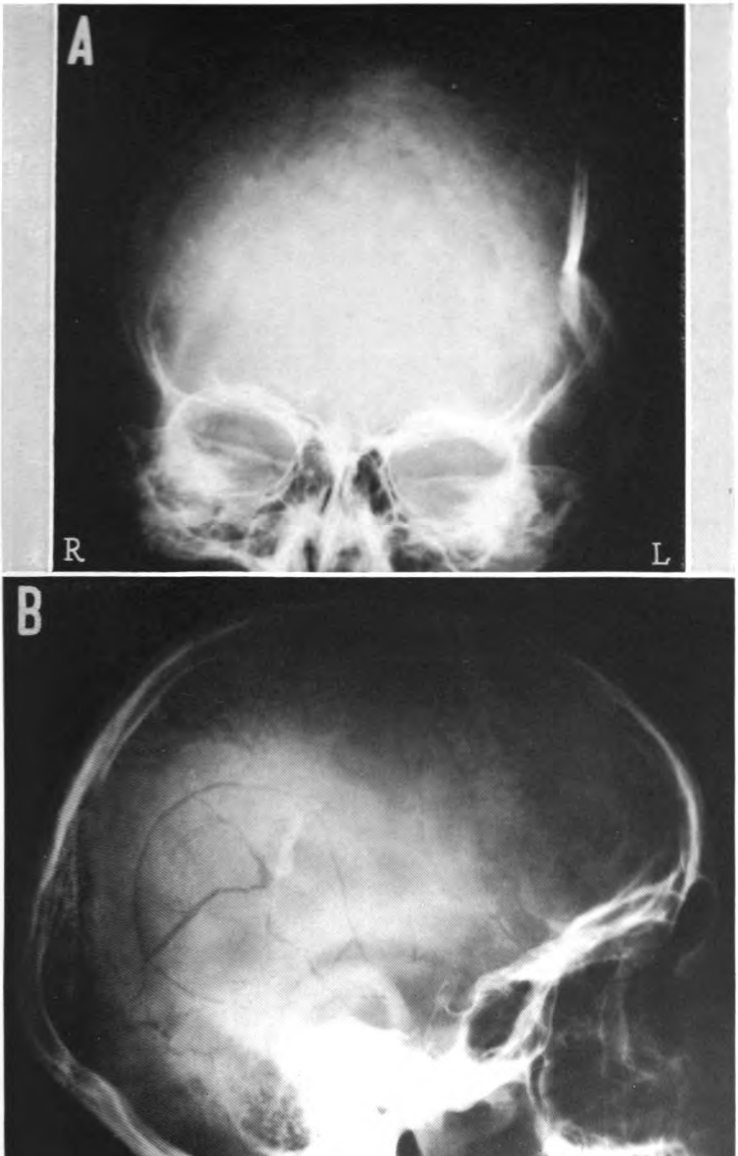


PLATE 23.—Depressed stellate fracture, left parietal bone.

usually prevents the devastating bone lysis shown in Plate 24, *A*.

Specific granulomatous lesions of the adult skull are rare, and roentgenologic findings are not diagnostic.

NEOPLASTIC LESIONS OF THE CRANIUM. Osteomas arise from either the inner or the outer table of the skull and, although usually small and round, show wide variations in size and shape. The outstanding characteristic of this tumor is localized overproduction of bone which is seen on the roentgenogram as an area of ivory-like increase in density. The lesion has clinical significance only if it encroaches on important soft tissue structures such as the cranial nerves. Differentiation between an osteoma and reactive osseous overgrowth associated with a meningioma is sometimes difficult.

Other benign neoplasms such as angiomas and intradiploic epidermoids ordinarily produce localized areas of decreased density due to limited bone destruction.

Sarcoma of the cranial vault, which fortunately is rare, may be either osteolytic (purely destructive) or osteoblastic (both destructive and proliferative). In the osteolytic type, differentiation from acute osteomyelitis may be impossible on the basis of roentgenologic findings alone. In the osteoblastic variety, spicules of tumor bone occasionally are seen radiating out into the scalp, producing a bizarre appearance.

Multiple myeloma is a neoplastic disease of bone marrow elements—notably the plasma cell. The flat bones of the skull frequently harbor nests of these cells within numerous areas of bone destruction which classically appear on roentgenograms as small pea-sized, discrete, rounded zones of decreased density (Plate 24, *B*). Divergence from this typical appearance is occasionally encountered, the lesions varying from tiny, pinhead foci to large, irregular zones of bone destruction.

Metastatic neoplasm may be conveniently classified as osteolytic or osteoblastic in type. Osteolytic metastases usually arise secondary to carcinoma of the breast, thyroid, lung or genitourinary tract. They ordinarily produce relatively large foci of bone destruction but not infrequently simulate multiple myeloma. In children, metastatic neuroblastoma (sympathicoblas-

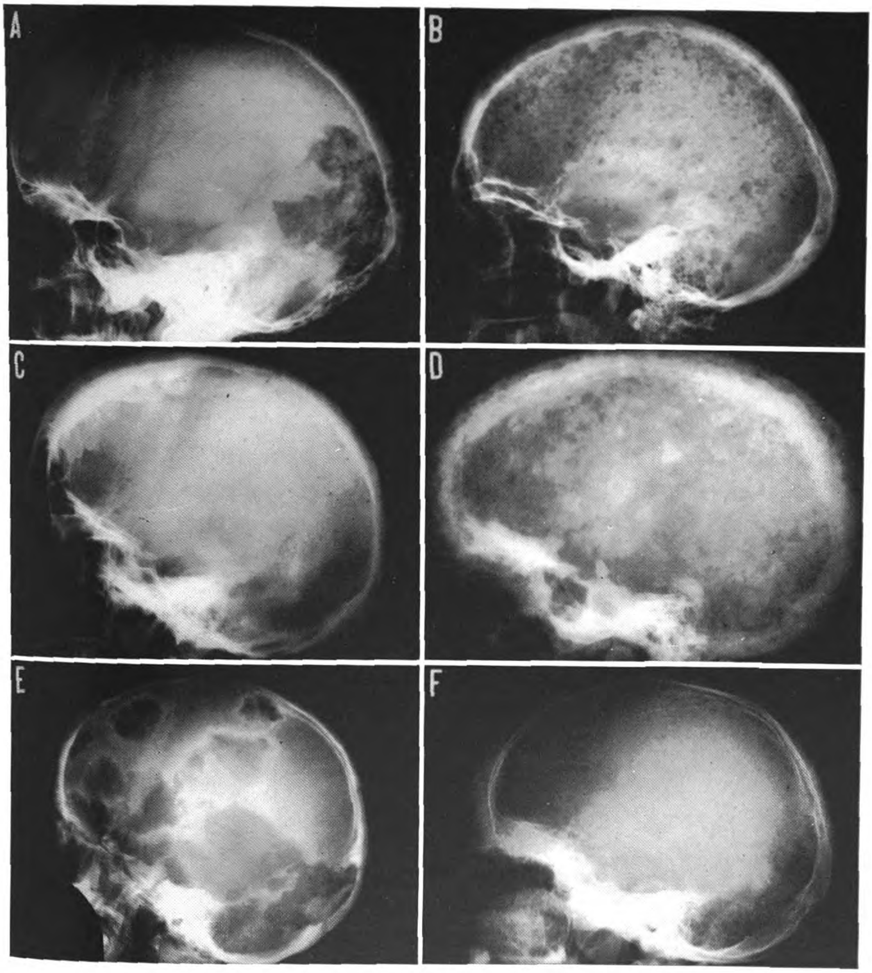


PLATE 24.—*A*, hematogenous osteomyelitis, parieto-occipital region. *B*, multiple myeloma. *C*, hyperostosis frontalis interna. *D*, Paget's disease. *E*, chronic reticuloendotheliosis. *F*, Mediterranean anemia.

toma), usually arising in the adrenal medulla, often involves both the skull and brain, producing a combination of fine, moth-eaten bone destruction and separation of sutures which is virtually diagnostic.

Osteoblastic metastases, which apparently stimulate bone production in large amounts, are commonly associated with carcinoma of the prostate. Their poorly defined zones of increased density create a coarsely mottled effect throughout the cranial bones. Other forms of neoplasia rarely simulate this appearance.

MISCELLANEOUS LESIONS OF THE CRANIUM. Hyperostosis on the inner table of the frontal bone is a common finding in women of all ages, but particularly in the older age groups. Bilaterally symmetrical scalloped overgrowth of bone characterizes this abnormality, the etiology and clinical significance of which remains to be proved. The woman with the extensive hyperostosis frontalis shown in Plate 24, *C*, complained only of vague headaches.

Osteitis deformans (Paget's disease) produces a classic roentgenologic appearance when the disease is in its advanced stage. Pronounced thickening of the outer table and the diploe results from the replacement of normal bone in these areas by the highly vascular, porous bone which characterizes the disease. In addition to this thickening, the roentgenogram shows multiple rounded shadows of increased density which have been likened to "tufts of cotton." Surrounding these tufts are annular zones of diminished density (Plate 24, *D*).

Osteoporosis circumscripta, typified by rather large, well-demarcated shadows of decreased density in the outer table of the skull, is probably an early, purely osteolytic expression of Paget's disease.

Polyostotic fibrous dysplasia characteristically produces diffuse thickening of the frontal bone, base of the skull and occipital bone in addition to other skeletal lesions. The combination of fibrous skeletal foci, hyperpigmentation of the skin (café au lait spots) and precocious sexual development in females is now widely recognized as Albright's syndrome.

Hyperparathyroidism produces interesting skull changes in the form of miliary zones of osteoporosis which markedly accentuate the normal diploic pattern. One should search for disappearance of the lamina dura, a thin white line around the root of each tooth, in the early stages of this disease.

Cretinism is another endocrine disorder the trade mark of which is frequently stamped in the skull. Roentgenograms of children with this disorder invariably reveal delayed dentition and retarded closure of the fontanels.

Rickets is characterized by incomplete calcification of bone throughout the entire skeletal system, including the cranium. Large amounts of poorly mineralized osteoid tissue deposited in layers on the outer table of the skull at the frontal and parietal eminences account for the "bossing" which is evident clinically.

Reticuloendotheliosis of the Schüller-Christian type, sometimes called xanthomatosis, is a disturbance of unknown etiology in which cholesterol is stored within hyperplastic reticulum cells. These lipid-containing histiocytes partially replace various normal tissues, among which are the bones of the skull, pelvis, ribs and femurs. The lesions in the skull are most characteristic, appearing on the roentgenogram as round or irregular, sharply defined areas of decreased density having a maplike configuration. These features are shown in *E* (Plate 24); the bands of increased density surrounding the destructive lesions apparently represent evidence of partial repair.

Other types of reticuloendotheliosis, such as the relatively benign eosinophilic granuloma and the highly malignant Letterer-Siwe disease of infants, cause similar lesions in the cranial vault as well as other portions of the skeleton. It has been suggested that all of these diseases are related—hence the common designation of reticuloendotheliosis.

Mediterranean anemia (Cooley's anemia) produces dramatic changes in the skull as the direct result of bone marrow hyperplasia. The diploic space becomes widened and the diploic markings are accentuated (Plate 24, *F*). Atrophy of the outer table occasionally occurs, and in such instances radiating spicules of diploic bone are deposited perpendicular to the skull surface.

Similar changes are sometimes seen in other chronic hemolytic anemias such as sickle cell anemia.

INTRACRANIAL LESIONS

Although intracranial tumors constitute only 5 per cent of all forms of neoplasm diagnosed at the University of Michigan, these lesions are discussed because of the unique part played by roentgen methods in their detection. When searching for brain tumors, a preliminary roentgenographic survey of the skull is always made despite the fact that these plain films show evidence of the tumor in only 25 per cent of cases. A much greater degree of accuracy in both identification and localization of intracranial lesions is achieved by employing three supplementary procedures known as encephalography, ventriculography and angiography. Each of these methods has individual merit, but the diagnostic value of all depends on the following principle. *A space-occupying lesion within the rigid cranium sooner or later produces generalized or localized roentgenographic changes in the cranium or some normal intracranial structure which has been rendered visible by physiologic calcification or artificially introduced contrast medium.*

ROUTINE SKULL FINDINGS. Generalized signs of an expanding brain lesion are the result of increased intracranial pressure. This may be due to the tumor mass and associated brain edema, but more often it is produced by obstruction to the normal outflow of cerebrospinal fluid with resultant dilatation of the cerebral ventricles (internal hydrocephalus). Roentgenologically, one may see spreading of the cranial sutures, providing ossification of these structures has not occurred (Plate 25, *A*). Otherwise there may be thinning of the skull bones which conforms to the cortical convolutions; this in itself is a most untrustworthy sign but is of some value when observed in conjunction with other abnormalities.

As a rule, localized roentgenographic changes furnish much more reliable evidence of an intracranial lesion. One of the most convincing signs which can be found is displacement of some

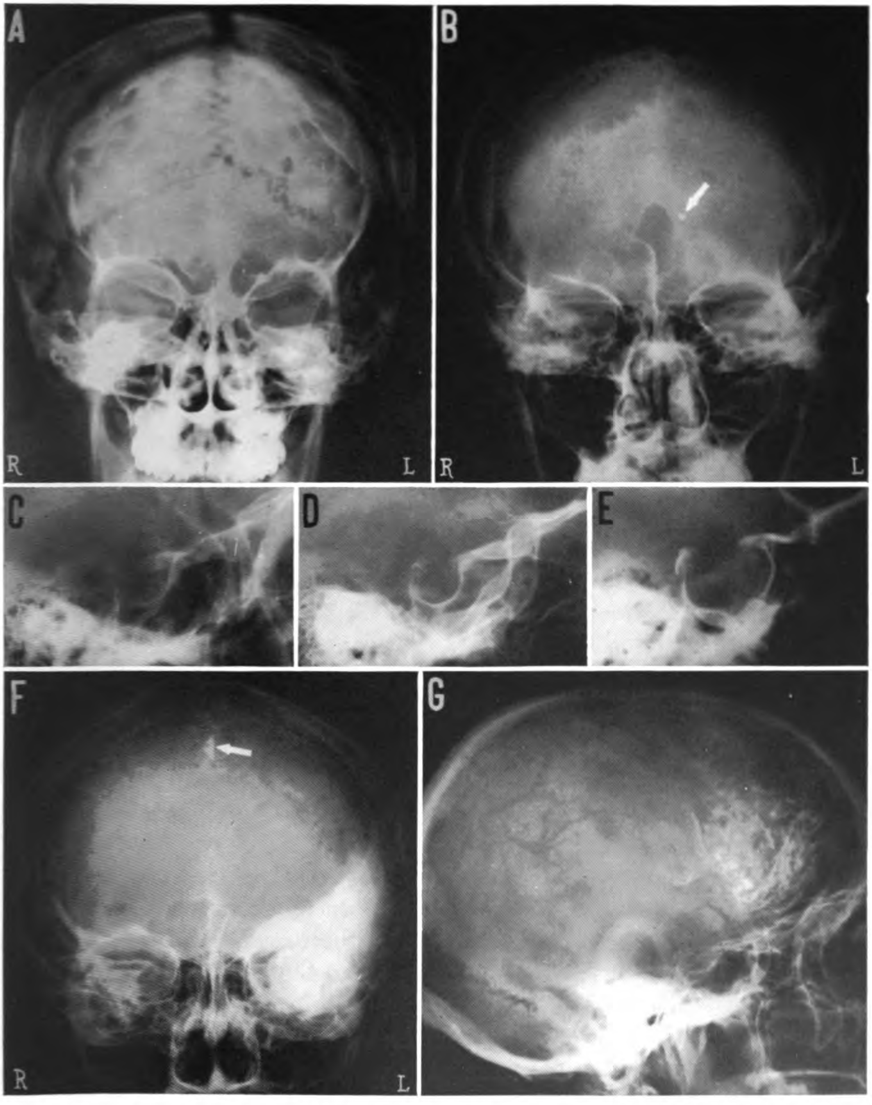


PLATE 25.—*A,* spread cranial sutures. *B,* displaced pineal gland (arrow). *C,* extrasellar erosion. *D,* normal sella turcica. *E,* intrasellar erosion. *F,* left sphenoid wing meningioma; calcification in falx (arrow). *G,* partially calcified brain tumor.

physiologic calcification. This is particularly true of the commonly calcified pineal gland, the midline position of which makes recognition of significant displacement relatively simple. In Plate 25, *B*, striking displacement of the calcified pineal body to the left is due to a space-occupying lesion on the right side. Immediately following surgical removal of the intracranial lesion, which in this instance was a subdural hematoma, the pineal body returned to its normal midline position.

In adults the earliest and most reliable sign of increased intracranial pressure is extrasellar erosion. This change is usually caused by the pulsating pressure of a dilated third ventricle on the dorsum sellae and is characterized by progressive decalcification, blunting, thinning and straightening of that structure until it eventually disappears. The moderate degree of extrasellar erosion shown in *C* occurred in a patient with a posterior fossa tumor which produced marked internal hydrocephalus. (Compare *C* with the normal pituitary fossa in *D*.)

Intrasellar erosion, the most helpful roentgenologic sign in the diagnosis of chromophobe and eosinophilic pituitary adenomas, is readily recognized by equal, outward displacement of the walls of the sella turcica in all directions. Observe the huge sella of the acromegalic in Plate 25, *E*. In this type of erosion the dorsum sellae usually escapes destruction until the pituitary fossa has ballooned to immense proportions. Incidentally, basophilic adenomas of the pituitary never become large enough to produce intrasellar erosion.

Bone immediately adjacent to a superficial intracranial neoplasm may show localized destructive or proliferative changes which not only denote the presence of the tumor but also serve to identify it as to type. For example, acoustic neuromas at times cause visible widening of the internal auditory canal as well as various degrees of destruction in the apex of the petrous bone. Meningiomas often produce focal hyperostosis when they occur at one of their favorite sites, such as the olfactory groove, a sphenoid ridge or the margin of the sagittal sinus. The marked increase in density of the left sphenoid bone in Plate 25, *F*, represents typical hyperostosis associated with a meningioma in this

region. Note, too, the small plaque of physiologic calcification in the falx cerebri (arrow).

Asymmetrical widening of arterial grooves and diploic venous channels in the skull is another helpful localizing sign of superficial vascular tumors. It is not seen very often, however, and sometimes occurs as a development variation.

Visible calcification occurs in only 10 per cent of all brain tumors, but in cases in which it is seen its localizing value is clearly evident. Plate 25, *G*, shows a large calcified oligodendroglioma in the left frontal lobe.

The craniopharyngioma (Rathke's pouch tumor) is another good example of a calcified intracranial tumor. This lesion, which is usually found in children, produces intrasellar erosion and intrasellar or suprasellar calcification in at least 60 per cent of cases.

INTRACRANIAL PNEUMOGRAPHY. In 1917, Dandy conceived the now widely accepted plan of introducing air into the ventricles of the brain to make them visible on roentgenograms. Air may be injected directly into the ventricles through a small trephine opening in the skull (ventriculography), or it may be introduced indirectly via the lumbar puncture route with the patient in a sitting position (encephalography).

Encephalography has one advantage over ventriculography in that it outlines the subarachnoid spaces (basilar cisterns and sulci) as well as the ventricles. This permits the diagnosis of superficial lesions such as cerebral atrophy and arachnoiditis in addition to neoplasms, abscesses, etc. The postero-anterior and right lateral encephalographic projections in Plate 26, *A*, show moderate dilatation of the left lateral ventricle and marked prominence of the subarachnoid channels over the left cerebral hemisphere due to cerebral atrophy. Similar but less extensive changes are present on the right side.

Unfortunately, lumbar puncture is contraindicated in patients with increased intracranial pressure because of the danger of herniating the lower structures of the brain through the foramen magnum and causing sudden death. Since most brain tumors have associated increased intracranial pressure, ventriculography auto-

matically becomes the method of choice in such instances. This procedure yields over 90 per cent accuracy in the localization of all forms of space-occupying intracranial lesions.

Because it is impossible to replace all of the cerebrospinal fluid by air, roentgenograms in multiple projections are required in both types of cerebral pneumography. Fluid remaining in the ventricular system will always seek the most dependent level and conversely, the injected air will rise to outline the most superior portions of the ventricles as well-defined shadows of decreased density. Thus, by moving the patient's head into different positions and using suitable projections, it is possible to outline all portions of the ventricular system. Of course, the importance of stereoscopic projections cannot be overemphasized.

Pneumographic localization of brain tumors is accomplished by carefully evaluating displacement, distortion and deformity of the four air-filled cerebral ventricles and the aqueduct of Sylvius. In general, hemisphere lesions produce shift of the lateral ventricles and third ventricle toward the opposite side. For example, in Plate 26, *B*, a glioma of the right frontoparietal region has displaced the ventricles far to the left side. In lateral projections, none of which is shown, a localized filling defect in the right lateral ventricle identified the position of the tumor in the anteroposterior plane.

Tumors of the third ventricle produce well-defined filling defects within this ventricle and pronounced symmetrical dilatation of the lateral ventricles without displacement. Posterior fossa tumors locally distort the fourth ventricle and aqueduct and cause the greatest degree of symmetrical dilatation of the lateral and third ventricles. The patient whose right lateral ventriculogram is shown in Plate 26, *C*, has a medulloblastoma displacing the fourth ventricle and aqueduct anteriorly. All of the ventricles are dilated, which accounts for the fact that they are so well delineated.

When gas ventriculography fails to differentiate a posterior third ventricle tumor from one in the posterior fossa, positive contrast ventriculography may prove helpful. In this highly specialized and rarely used procedure, a small amount of an opaque medium such as Pantopaque® is injected into a lateral

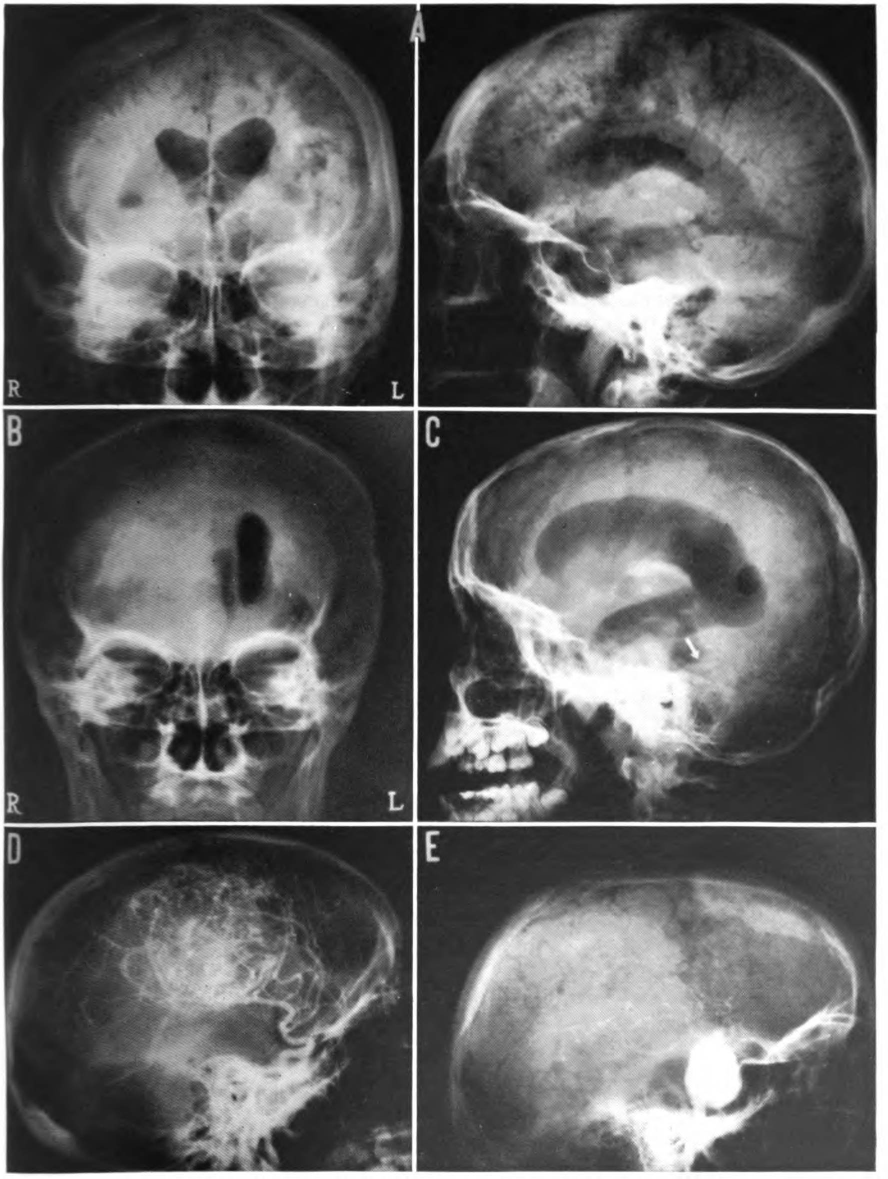


PLATE 26.—*A,* cerebral atrophy. *B,* frontal lobe tumor. *C,* posterior fossa tumor. *D,* angiogram, vascular tumor. *E,* angiogram, carotid aneurysm.

ventricle. Then, under fluoroscopic control and with judicious rotation of the patient's head, the contrast medium is guided into the third and fourth ventricles.

CEREBRAL ANGIOGRAPHY. This procedure, introduced by Moniz in 1927, is also a highly specialized but thoroughly utilitarian and widely used technic whereby the cerebral blood vessels are opacified by the injection of a suitable opaque medium into the internal carotid artery. Properly exposed roentgenograms show these vessels to have a fairly constant pattern which is characteristically distorted by supratentorial space-occupying lesions. Furthermore, the increased number of blood vessels within certain vascular tumors sometimes serve to localize the lesion in a more direct and more spectacular manner. In Plate 26, *D*, the frontoparietal neoplasm proved to be a cystic glioblastoma.

Vertebral arteriography for the detection of posterior cerebral or cerebellar lesions and dural sinus venography for the identification of sagittal sinus thrombosis are more recently developed cerebral angiographic technics of distinctly limited value.

MISCELLANEOUS INTRACRANIAL CONDITIONS. A number of diversified intracranial lesions other than tumors can be diagnosed by roentgenographic methods. Brain abscesses usually produce changes similar to those described in conjunction with neoplasms. Tuberculoma, toxoplasmosis, tuberous sclerosis, torulosis, angiomatosis and cytomegalic inclusion disease are rare causes of intracranial calcification. The various forms of congenital hydrocephalus are best evaluated by intracranial pneumography. Porencephalic cysts appear as air- and fluid-containing cavities communicating with the ventricular system. Arachnoiditis classically causes obliteration of the subarachnoid pathways normally outlined by encephalography. Gliosis (scarring) of the brain due to trauma or inflammation may produce retraction of the ventricular system toward the involved area. Direct evidence of intracranial aneurysms is afforded only by suitably exposed angiograms. As an example, Plate 26, *E*, shows a large aneurysm of the right internal carotid artery nicely outlined by opaque medium.

READING LIST

CAFFEY, J.: *Pediatric X-ray Diagnosis* (3d. ed.; Chicago: Year Book Publishers, Inc., 1956).

CAMP, J. D.: Pathologic non-neoplastic intracranial calcification, J.A.M.A. 137:1023–1031, July 17, 1948.

——: Significance of intracranial calcification in roentgenologic diagnosis of intracranial neoplasms, Radiology 55:659–668, November, 1950.

DANDY, W. E.: Ventriculography following the injection of air into the cerebral ventricles, Ann. Surg. 68:5–11, 1918.

——: Roentgenography of the brain after injection of air into the spinal canal, Ann. Surg. 70:397–403, 1919.

DAVIDOFF, L. M., AND DYKE, C. G.: *The Normal Encephalogram* (3d ed.; Philadelphia: Lea & Febiger, 1950).

——, AND EPSTEIN, B. S.: *The Abnormal Pneumoencephalogram* (Philadelphia: Lea & Febiger, 1950).

DYKE, C. G., AND CHILDE, A. E.: The roentgen-ray diagnosis of diseases of the skull and intracranial contents, in GOLDEN, R. (ed.): *Diagnostic Roentgenology* (Baltimore: Williams & Wilkins Company, 1952).

ECKER, A., AND RIEMENSCHNEIDER, P. A.: *Angiographic Localization of Intracranial Masses* (Springfield, Ill.: Charles C Thomas, Publisher, 1955).

ETTER, L. E.: *Atlas of Roentgen Anatomy of the Skull* (Springfield, Ill.: Charles C Thomas, Publisher, 1955).

GILBERTSON, E., AND GOOD, C. A.: Roentgenographic signs of tumors of the brain, Am. J. Roentgenol. 76:226–247, August, 1956.

HODGES, F. J.; HOLT, J. F.; BASSETT, R. C., AND LEMMEN, L. F.: Reliability of brain tumor localization by roentgen methods, Am. J. Roentgenol. 71:624–630, April, 1954.

JOHNSON, V. C., AND LIST, C. F.: Ventriculographic localization of intracranial tumors: I. Tumors involving the posterior part of the third ventricle and thalamus. Am. J. Roentgenol. 38:77–91, July, 1937; II. Tumors of the aqueduct, pons and cerebello-pontine angle, ibid. 40:348–356, September, 1938; III. Tumors of the cerebellum and fourth ventricle, ibid. 43:346–355, March, 1940.

KAHN, E. A.; BASSETT, R. C.; SCHNEIDER, R. C., AND CROSBY, E. C.: *Correlative Neurosurgery* (Springfield, Ill.: Charles C Thomas, Publisher, 1956).

LINDGREN, E.: Radiologic examination of the brain and spinal cord, Acta radiol. supp. 151, Stockholm, 1957.

PENDERGRASS, E. P.; SCHAEFFER, J. P., AND HODES, P. J.: *The Head and Neck in Roentgen Diagnosis* (Springfield, Ill.: Charles C Thomas, Publisher, 1956).

RITVO, M.: *Roentgen Diagnosis of Diseases of the Skull* (New York: Paul B. Hoeber, Inc., 1949).

RUBIN, P., AND HOLT, J. F.: Secretory sialography in diseases of the major salivary glands, Am. J. Roentgenol. 77:575–598, April, 1957.

SAMUEL, E.: *Clinical Radiology of the Ear, Nose and Throat* (New York: Paul B. Hoeber, Inc., 1952).

SCHWARTZ, C. W., AND COLLINS, L. C.: *The Skull and Brain Roentgenologically Considered* (Springfield, Ill.: Charles C Thomas, Publisher, 1951).

Shanks, S. G., and Kerley, P.: *A Textbook of X-ray Diagnosis,* vol. 1: *The Head and Neck* (3d ed.; Philadelphia: W. B. Saunders Company, 1958).

Young, B. R.: *The Skull, Sinuses and Mastoids* (Chicago: Year Book Publishers, Inc., 1948).

4

The Spine and Extremities

THE SPINE

ALL BUT TWO of the vertebrae which make up the spinal column at birth consist of three primary centers of ossification—a central one for the body and a lateral one for each side of the neural arch. The unique features of the atlas and the axis make them the only exceptions to the usual pattern of ossification. Obviously, the roentgen appearance of the newborn spine differs considerably from that of the adult spine; in the vertebral segments of the adult spine not only the primary centers but also eight to 12 secondary centers have appeared and subsequently merged. This complex ossification does not occur abruptly but takes place gradually over a period of about 25 years. The roentgenologist must be thoroughly conversant with the normal variations related to age if he is to evaluate the status of the spine with accuracy. Differences in the contour of vertebral bodies and alterations in the relative width of intervertebral disk spaces which are characteristic of particular age periods, as well as progressive changes in the extent of regional curves, are examples of normal variations which must be considered. No more than a general understanding of such matters is necessary for the student, and it is hoped that the illustrations in Plate 27 will aid in the acquisition of that basic information. The roentgenographic appearance of the entire spine of a newborn infant in anteroposterior and in lateral projection is shown in *A*. Compare the lumbosacral region with that of a 25 year old adult shown in *B*.

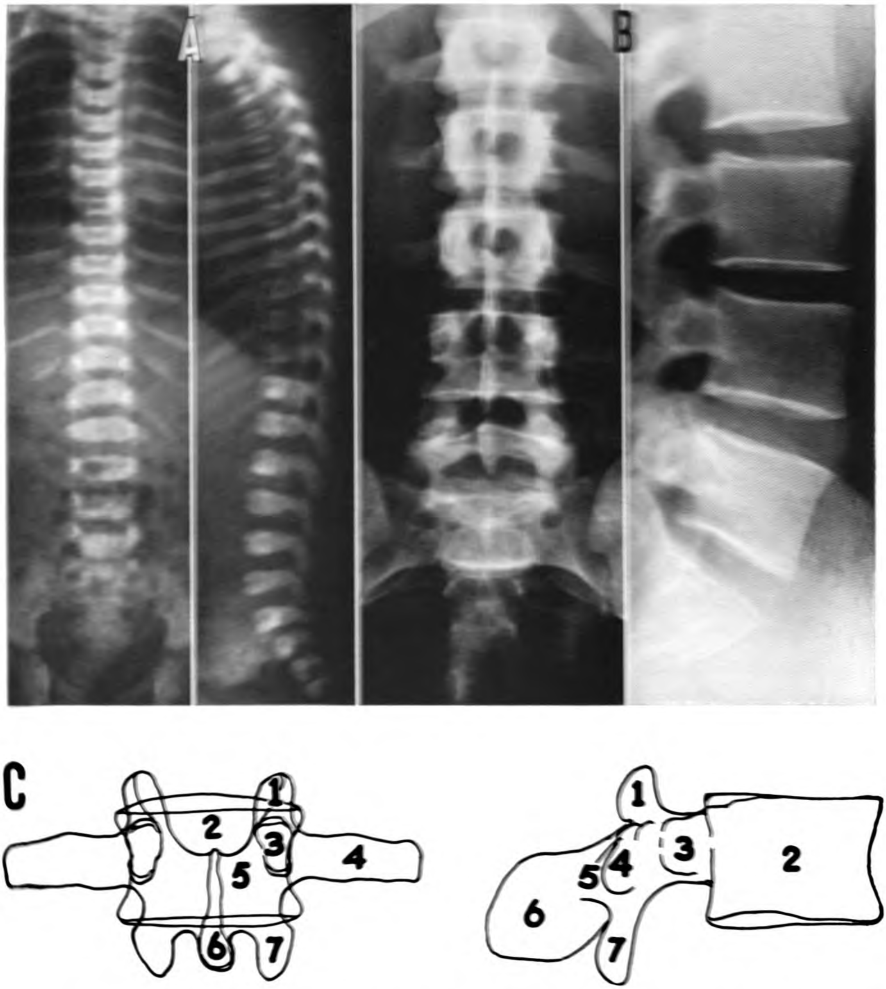


PLATE 27.—*A*, spine of newborn infant. *B*, lumbar spine of young adult. *C*, typical adult lumbar vertebral segment: *1*, superior articulating facet; *2*, vertebral body; *3*, pedicle; *4*, transverse process; *5*, lamina; *6*, spinous process; *7*, inferior articulating facet.

For more detailed study, diagrammatic representation of a typical adult lumbar-vertebral segment is shown in *C*. (*1*, superior articulating facet; *2*, vertebral body; *3*, pedicle; *4*, transverse process; *5*, lamina; *6*, spinous process; *7*, inferior articulating facet.) To avoid diagnostic errors, one must scrutinize the component parts of each individual vertebra when examining the spine.

In adults the preparation of satisfactory spine roentgenograms presents difficult problems of technic that are related to multiplicity of articulations and processes to be shown, complex curves which must be resolved in a single plane in any one projection and great body thickness which requires relatively long exposure times. Regardless of the particular site of suspected abnormality, the first step in x-ray examination of the vertebral column should be anteroposterior and lateral projections of the entire structure. This is required because it is not possible in all instances to localize lesions accurately on the basis of symptoms. Stereoscopic oblique projections show the articulating facets and intervertebral foramina to good advantage, but such views are used only in selected cases. Exposures through the open mouth are necessary to demonstrate the atlas and axis in the frontal plane.

ANOMALIES. Minor developmental faults are so commonplace that an anatomically perfect spine is a distinct oddity. Some of the defects visible by x-ray, such as extra vertebrae, cervical ribs and asymmetrical articulating facets, are obviously of congenital origin even to the uninitiated; others may easily be misinterpreted as significant lesions.

Spina bifida occulta, faulty fusion of the laminae, is particularly apt to occur in the fifth lumbar and first sacral segments (Plate 28, *A*). When this anomaly is extensive, associated meningocele or myelomeningocele may be found. An ununited secondary vertebral epiphysis may be difficult to distinguish from an avulsion fracture or a detached hypertrophic spur.

Sacralization is the unilateral or bilateral incorporation of the fifth lumbar transverse process with the lateral masses of the sacrum. Lumbarization of the first sacral segment implies the separation of this vertebra from the remainder of the sacrum

and, thus, the formation of an extra lumbar segment. Short, anomalous lumbar ribs may be mistaken for fractures of transverse processes or, if the ribs are long, for evidence of a supernumerary thoracic vertebra.

So-called "block vertebra" denotes partial or complete failure of segmentation of adjacent bodies; the result is a large, more or less double vertebra with decreased anteroposterior diameter like the one indicated by the arrow in Plate 28, *B*. As is often the case in the thoracic and lumbar regions, the anomaly in this patient was an accidental finding of no clinical importance. On the other hand, improper segmentation of cervical vertebrae may be associated with a wide variety of significant symptoms.

The hemivertebra shown in *C* is another interesting error in segmentation which, because of its eccentric position, tends to produce abnormal spinal curvature.

ABNORMAL CURVATURE. The normal anteroposterior curvatures of the spine, viz., cervical and lumbosacral lordosis and thoracic kyphosis, frequently are accentuated either by significant disease or by such commonplace causes as poor posture and the normal aging process. Roentgenographic examination may be helpful in the differentiation of these various etiologic factors.

Lateral curvature of the spine (scoliosis) is always abnormal and is invariably associated with rotation of the vertebrae, hence the term rotoscoliosis. This abnormality, which usually consists of a primary curvature and of a secondary compensatory curvature, may be structural, owing to some developmental fault in vertebral ossification; paralytic, owing to muscle imbalance of neurogenic origin, or idiopathic. Roentgenograms are widely used to determine the type of scoliosis in a given instance and subsequently to record the results of orthopedic treatment.

INTERVERTEBRAL DISK ABNORMALITIES. There is no true synovial joint between adjacent vertebral bodies. The clear space seen in roentgenograms is occupied by the radiolucent intervertebral disk. This consists of a jelly-like nucleus pulposus tightly encased within an envelope of tough fibrocartilage. Because of this unique structure the disks have the properties of

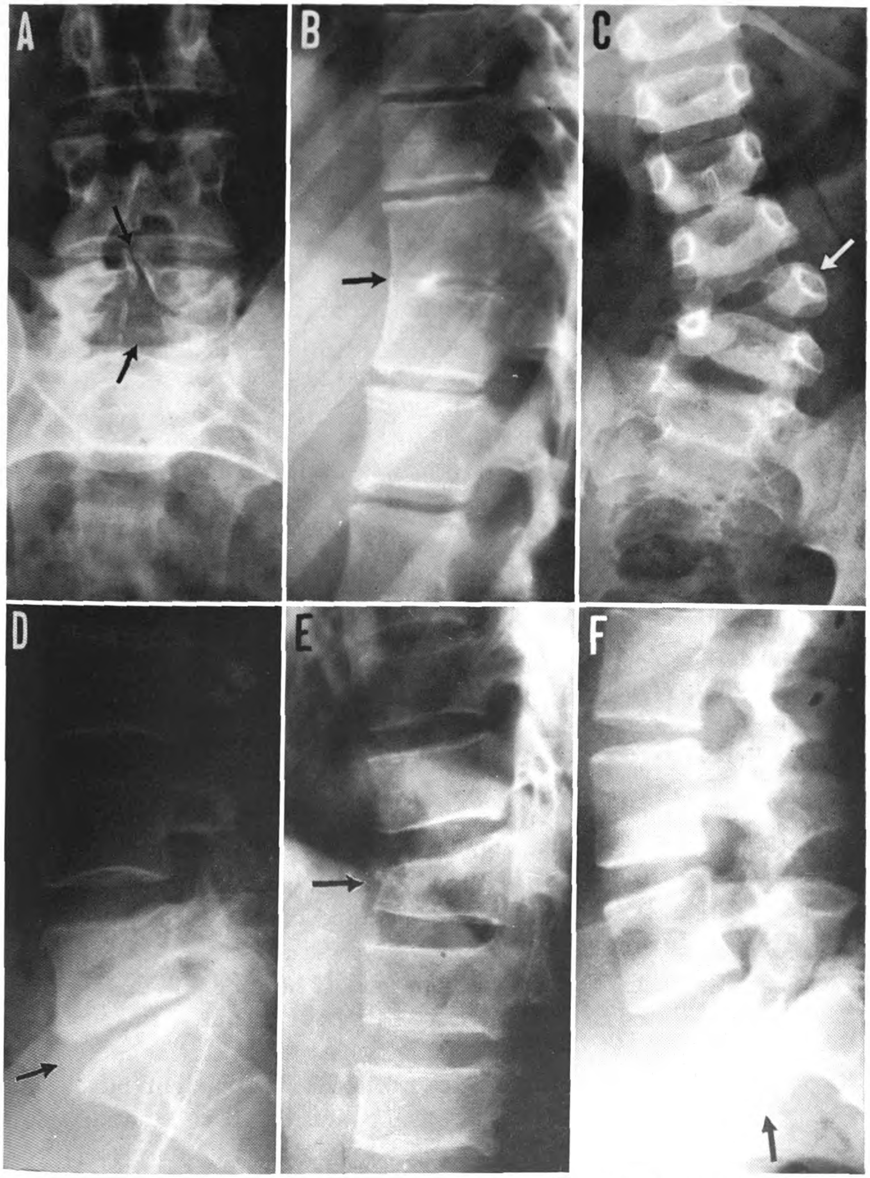


PLATE 28.—*A*, spina bifida occulta. *B*, block vertebra. *C*, hemivertebra. *D*, reduced lumbosacral disk space. *E*, compression fracture. *F*, spondylolisthesis.

well-constructed shock absorbers, but they are not invulnerable to injury, especially in the cervical and lumbar regions. Severe trauma may cause rupture of the annulus fibrosus and herniation of the nucleus pulposus in any direction, conditions manifested roentgenologically by visible reduction of the intervertebral disk space. If herniation into contiguous cancellous bone occurs, a localized, rounded defect called Schmorl's node is produced in the vertebral body.

Posterior herniation of the nucleus pulposus into the neural canal at the lumbosacral junction may cause pressure on nerve roots producing typical clinical signs and partial obliteration of the intervertebral disk space. It should be remembered, however, that reduction of the lumbosacral disk space may also occur as a developmental variation of no clinical consequence. In Plate 28, *D*, there is pronounced reduction in the vertical height of the lumbosacral disk without symptoms or signs referable to the low back region.

FRACTURES AND DISLOCATIONS. All patients with back injuries deserve the benefit of adequate roentgenologic examination. Clinical findings following trauma seldom give an accurate representation of underlying vertebral damage, and not infrequently roentgenograms lead to the detection of unsuspected fractures. If such injuries go untreated, crippling sequelae may develop in later years.

Most spine fractures are of the compression type in which the anterior vertical height of a body is reduced, producing a wedge-shaped deformity that is visible in lateral projection (Plate 28, *E*). Often no fracture line is visible, and in such cases it may be impossible to distinguish between recent and old injury. The extent of callus deposition is of little help in this regard, because callus is never produced in great quantity. In compression fractures there is no associated reduction of the intervertebral disk space, and this feature helps to rule out infectious processes which almost always involve the disk. Considerable difficulty may be encountered in distinguishing compression of osteoporotic vertebrae in the aged patient from the vertebral collapse caused by an underlying metastatic neoplasm.

Sometimes spine injuries are of a shearing nature, in which case fractures of the articulations associated with dislocation are apt to occur. This type of injury predisposes to spinal cord damage, and thus narrowing of the neural canal represents a significant roentgenographic observation. However, it is to be remembered that, after shearing or crushing the spinal cord, the involved vertebral segments may partially or completely snap back into their original positions. This combination of fracture and dislocation is particularly common in the cervical region.

Fractures of the transverse processes are largely confined to the third, fourth and fifth lumbar segments. Ordinarily, these fractures show little displacement and may be completely obscured by gas shadows in the intestinal tract.

SPONDYLOLISTHESIS. This is a fairly common condition in which the body of the fourth or fifth lumbar vertebra separates from its posterior neural arch and slips forward on the sloping surface of the vertebral body immediately beneath it. The break in the arch (spondylolysis), which must be present to permit spondylolisthesis, is usually found bilaterally in the isthmus between the superior and inferior articulating facets. Whether this break is congenital or acquired is debatable. Plate 28, *F*, illustrates pronounced spondylolisthesis at the lumbosacral junction. That the abnormality has been present for a long time is indicated by sclerosis of the vertebral margins adjacent to the slip and by erosion of the anterosuperior aspect of the first sacral segment.

ASEPTIC NECROSIS (OSTEOCHONDRITIS; JUVENILE EPIPHYSITIS). This disease of adolescence, characteristically generalized in the thoracic spine, involves the secondary epiphyses which ring the upper and lower margins of the vertebral bodies. The anterior portions of the epiphyses are fragmented, the vertebrae are wedged anteriorly and kyphosis is accentuated. Trauma may play a part in its etiology.

INFECTIOUS DISEASES. Tuberculosis, the commonest infectious lesion in the spine, classically manifests itself roentgenologically by reduction of an intervertebral disk space,

gradual destruction of adjacent vertebral bodies and formation of a fusiform paravertebral soft tissue shadow which represents an accumulation of caseous debris beneath the paraspinal ligaments. Ordinarily, these signs occur in the order given, and as the disease becomes more chronic, calcification within the paravertebral abscess may be seen. Localized kyphosis eventually may become pronounced if the disease is improperly treated. There is little or no evidence of new bone production. A fairly typical example of tuberculous spondylitis seen in lateral projection is shown in Plate 29, *A*. An anteroposterior projection of the lower dorsal spine in another patient with Pott's disease is presented in *B*. Here one sees little evidence of bone destruction, but a typical paravertebral abscess is clearly outlined.

In rare instances purulent osteomyelitis, brucellosis and typhoid fever involve the spine. For practical purposes, they cannot be differentiated from tuberculosis on the basis of roentgen findings alone.

RHEUMATOID SPONDYLITIS. The posterior articulations of the spine are true synovial joints and theoretically are subject to the same arthritic changes as the extremities. Actually, spinal rheumatoid arthritis (spondylitis rhizomelique) is relatively uncommon and in its early stages shows, roentgenologically, nothing more than osteoporosis of the articulating facets and narrowing of the spaces between them. Sacroiliac arthritis, recognized by marginal decalcification and mottling of these joints, is usually the earliest sign of rheumatoid spondylitis. Extensive calcification of longitudinal spinal ligaments eventually forms long, slender osteophytes which connect one vertebral body to another. This produces the typical "bamboo" spine (Plate 29, *C*).

Ordinarily it is easy to differentiate the paper-thin ligamentous calcification seen in advanced spondylitis rhizomelique from the common, bulky, spur-shaped osteophytes of hypertrophic spondylitis (Plate 29, *D*).

NEOPLASM. Primary neoplastic lesions of the spine are uncommon. In the benign group, osteochondroma, giant cell tumor and hemangioma are encountered most frequently. The

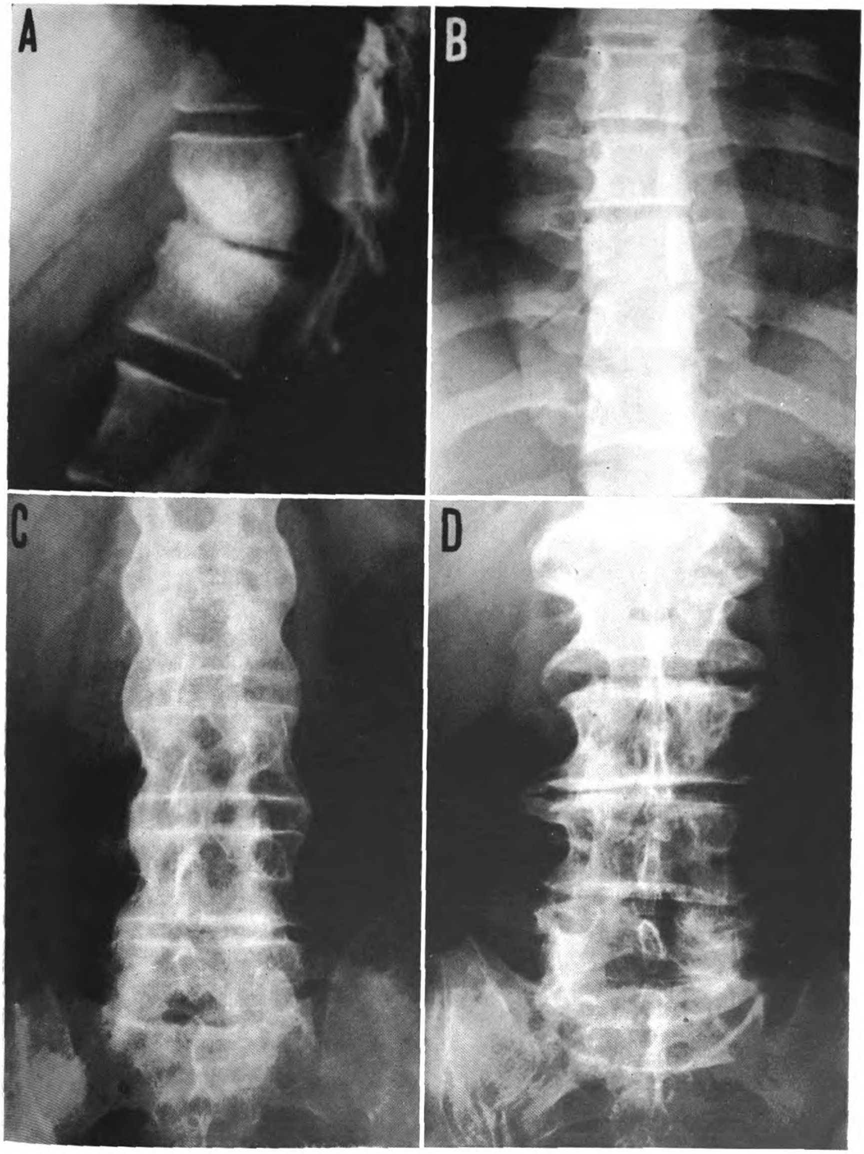


PLATE 29.—*A,* tuberculous spondylitis (Pott's disease). *B,* tuberculous paravertebral abscess. *C,* rheumatoid spondylitis. *D,* hypertrophic spondylitis.

characteristic vertical trabeculations of hemangioma are especially striking when observed on the roentgenogram.

Primary malignant tumors of the spine include solitary or multiple myeloma, other forms of lymphoblastoma, sarcoma and chordoma. The destructive lesions of multiple myeloma are widespread, small, rounded areas of decreased density scattered throughout various parts of the spine as well as the ribs, skull and bony pelvis. Hodgkin's disease, lymphosarcoma and leukemia involve the spine more often than was previously supposed; either destructive or proliferative changes may predominate. Fortunately, osteogenic sarcoma arising in a vertebra is rare. Like the other primary malignant neoplasms of the spine, the roentgenologic manifestations of sarcoma are not particularly characteristic.

Neoplastic metastases in the spine are relatively common, and their two chief sources—the breast and the prostate—exemplify contrasting roentgenographic changes which may occur. Metastases from carcinoma of the breast ordinarily produce multiple areas of irregular bone destruction and collapse of the involved vertebral bodies. Similar changes are seen at times in conjunction with thyroid carcinoma, bronchial carcinoma, hypernephroma and Ewing's tumor. Occasionally only a single spine metastasis may be evident, in a pedicle, perhaps, or other accessory process. Such lesions are notoriously difficult to detect and, without careful scrutiny of roentgenograms, may easily be overlooked. Carcinoma of the prostate almost invariably produces osteoblastic metastases which appear as fluffy shadows of increased density, frequently in the typical distribution in the spine and pelvis shown in Plate 30, *A*.

PAGET'S DISEASE. At times the "wooly" metastases of prostatic carcinoma may be difficult to differentiate from the bone changes in Paget's disease (osteitis deformans). This chronic, deforming skeletal disease commonly involves the spine and pelvis as well as the skull. Roentgenographically, one sees over-all increased density of involved bone with cortical thickening and prominent, coarse, wavy trabeculae. Involved vertebrae also are increased in over-all size.

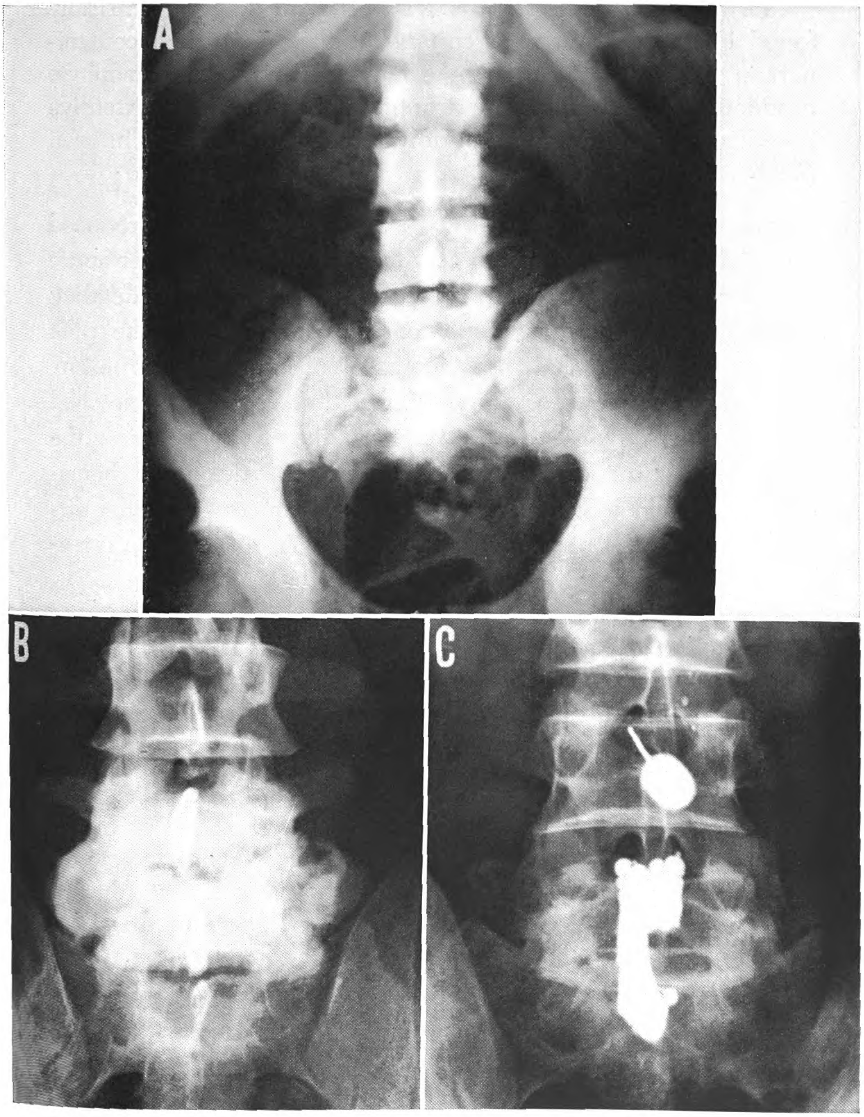


PLATE 30.—*A*, osteoblastic metastases from prostatic carcinoma. *B*, neurotrophic changes, lower lumbar spine. *C*, abnormal myelogram—herniation of lumbosacral nucleus pulposus.

NEUROTROPHIC LESIONS. Charcot joints, classically found in the extremities of certain tabetics, have their counterpart in the spine. Early changes consist of marginal osteophyte production, as in simple hypertrophic spondylitis. Later extensive fragmentation and eburnation of adjacent vertebrae will be seen (Plate 30, *B*).

MISCELLANEOUS LESIONS. Vertebral erosion produced by neighboring soft tissue tumors such as neurofibroma or aortic aneurysm may be characteristic enough to identify the offending lesion. On rare occasions, roentgenologic examination of the spine may show the so-called "fish vertebrae" of hyperparathyroidism, pituitary basophilism or adrenal cortical neoplasm; the notched defects and kyphosis of the various chondrodystrophies; the multiple fractures of osteogenesis imperfecta; the dense, homogeneous, chalklike osseous structure of osteopetrosis, or the disseminated islands of condensed bone which characterize osteopoikilosis.

MYELOGRAPHY. Contrast mediums such as lipiodol or pantopaque® may be injected into the subarachnoid space around the spinal cord by needle puncture of the lumbar region or the cisterna magna. A tilt table with fluoroscopic attachment facilitates the observation of the densely opaque material as it flows up and down the spinal canal. This procedure, called myelography, permits identification of spinal cord tumors producing either partial or complete obstruction of the spinal canal, posterior protrusions of herniated nuclei and filling defects due to arachnoid adhesions. Myelography is not a diagnostic procedure to be used indiscriminately, because the opaque medium acts as a definite irritant to the meninges. Ideally, the contrast material should be completely removed from the spinal cord after the examination.

In Plate 30, *C*, the large defect on the left side of the oil column within the neural canal is due to a herniated nucleus pulposus subsequently removed at operation. The opaque shadow above the iodized oil is a lumbar puncture needle which has been left in place to facilitate removal of the oil.

THE EXTREMITIES

The first parts of the human skeleton to be recorded on photographic plates by x-rays were the bones of the hand and foot. Their visibility in simple silhouette was an innovation, and the recognition of dislocations and of gross fractures was hailed as an outstanding advancement in medical diagnosis. The technic of roentgenographic examination was rapidly improved, and soon it became possible to demonstrate the delicate structural features within the phalanges and other small bones. With the advent of Potter's moving grid even the larger, more deeply situated bones could be studied in similar detail, and roentgenology became firmly established as the most important single agency in the diagnosis of skeletal disease.

It is obvious that the x-ray demonstration of skeletal parts can be of little benefit to the examiner who has not acquired some knowledge of normal bone structure—that without such knowledge he can scarcely hope to recognize any abnormality other than the most obvious ones. In the description of roentgenologic characteristics which are common to all tubular bones of the extremities, distinction must be made between the growing bones of children and adult bones in which active growth has ceased.

With but minor individual variations, every tubular bone, while still in the stage of active growth, consists of a long cylindrical part called the diaphysis, which flares at each end to form the metaphyses. Frequently and conveniently, the entire tube—diaphysis and terminal metaphyses—is spoken of as the shaft of a bone. Capping the shaft at each end is a mass of cartilage called the epiphysis. Pure cartilage is largely invisible in roentgenograms, but, as its conversion to bone progresses with age, a round or oval center of ossification will be seen within the epiphysis. Longitudinal growth occurs at the metaphyseal ends of the shaft, where the bone is seen to be denser than elsewhere. This is the zone of provisional calcification where the transformation of cartilage into bone goes on continuously, though at varying rate, until fusion of shaft and epiphysis brings an end to the period of growth. All of these structures are illustrated in

Plate 31, *A*, which shows the lower end of the femur and the tibia and fibula of a 2 year old child.

In an adult tubular bone the diaphysis appears much the same as it does in the child, the flaring of the metaphysis is less obvious and the epiphyses are fully ossified and solidly fused with their adjacent metaphyses. Sometimes a thin transverse streak of increased bone density persists throughout life to mark the site of epiphyseal fusion (Plate 31, *B*).

Three basic degrees of density can be recognized in the x-ray image of normal tubular bone at any age. The greatest density, a shadow of uniform whiteness, represents the compact cortex. The medullary cavity, recognizable through two layers of surrounding cortex, registers as a shadow, of considerably less density, which in the midportion of the shaft is nearly uniform. The metaphyses, which in adult life include the fused and fully ossified epiphyses, are still less dense and show the delicate trabecular pattern of cancellous bone. Normal periosteum is of equal density and therefore is indistinguishable in roentgenograms from surrounding and adjacent muscle, fascia and intracapsular joint structures.

Truly remarkable changes occur in bones during the growing period, and many of these are clearly apparent on x-ray examination. In addition to gradual alterations in the size and shape of bones as seen at birth, dozens of secondary ossification centers become visible up to age 15 or 16.

It is well to appreciate the fact that the normal sequence of events in growing bones follows a fairly well-defined time schedule which is definitely more rapid in girls than in boys. Furthermore, the behavior of certain diseases is so intimately related to osseous development that any significant change in the normal time schedule may in itself be of great diagnostic value. Several excellent standards of normal skeletal age have been prepared by various authorities on the subject, and these are of considerable help in evaluating the abnormal.

Ossification centers, as well as tiny accessory ossicles in the hands and feet that are so common they can scarcely be classed as anomalies, often invite erroneous interpretation as fractures.

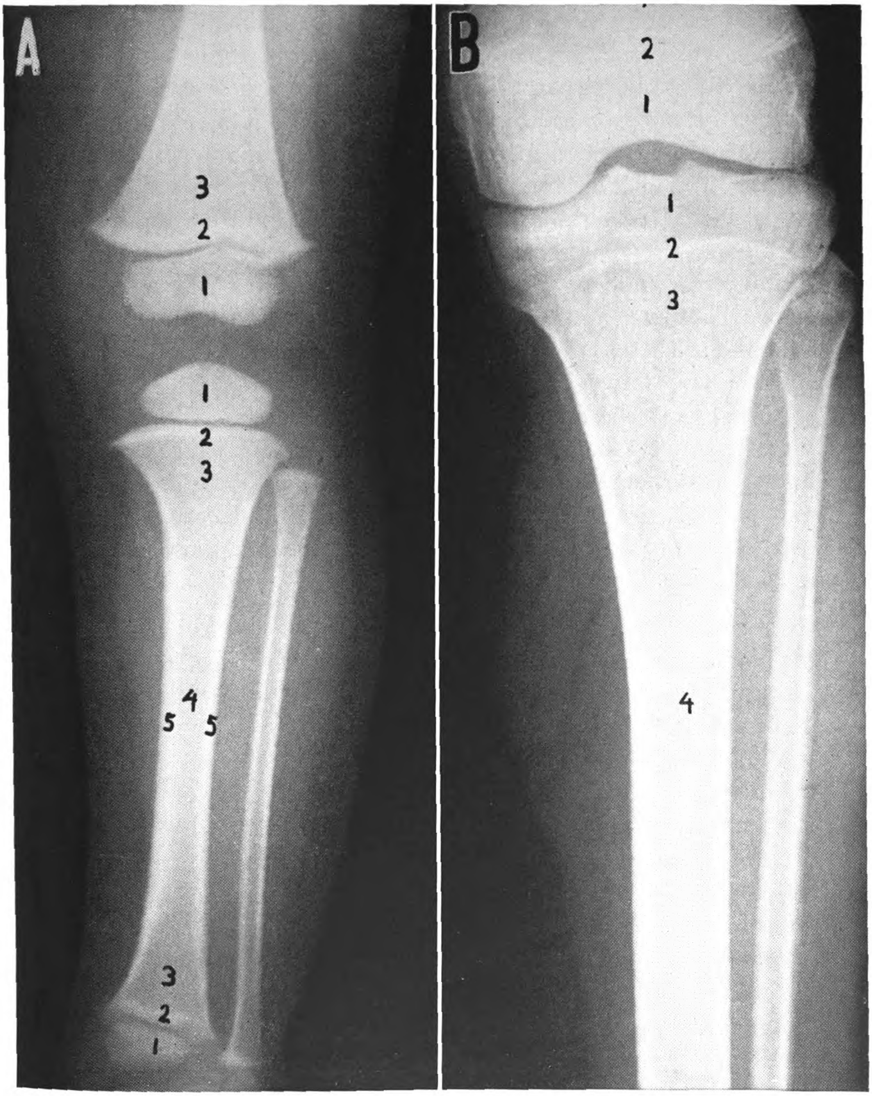


PLATE 31.—Topography of normal long bones. *A,* child, aged 2: *1,* epiphyseal ossification center; *2,* provisional zone of calcification; *3,* metaphysis; *4,* medullary cavity of diaphysis; *5,* cortex of diaphysis. *B,* adult: *1,* epiphysis; *2,* site of epiphyseal-metaphyseal fusion; *3,* metaphysis; *4,* diaphysis.

Inconstant sesamoids, such as the os fabella in the lateral head of the gastrocnemius, often simulate loose bodies within the joints. To avoid embarrassing misinterpretation of such manifestations of normal development, it is a wise practice to expose identical roentgenograms of the normal extremity as well as of the one in which disease is suspected.

It should be emphasized that in most types of bone disease, at any age level, there is a definite lag in the appearance of roentgenographic signs following the onset of clinical manifestations. The length of this latent period varies considerably in different diseases and in different individuals; it may be measured in days, in weeks or even in months.

Finally, it should be clearly understood that the roentgenologist is not the final court of appeal in every case of bone and joint disease. Although his diagnostic authority in this field can scarcely be overemphasized, neither his decisions nor the roentgenographic evidence on which he bases those decisions are infallible.

TRAUMATIC LESIONS. It is generally agreed that roentgenologic examination is mandatory in all instances of suspected fracture. Aside from their medicolegal value, roentgenograms yield precise information with regard to the type and age of fracture, the position of bone fragments, the extent of damage to articular surfaces and the presence or absence of associated dislocation, epiphyseal displacement and underlying bone disease. All these factors have a profound bearing on the plan of treatment, the prognosis and the ultimate outcome of a given fracture. What constitutes a complete roentgen examination varies with the individual case; but as a rule it is essential to have two views of the injured part, preferably at right angles to each other. In regions such as the shoulder and pelvis where lateral views are not feasible, stereoscopic anteroposterior projections are invaluable. Oblique or tangential projections are useful in the diagnosis of certain types of injury in the wrist, elbow, knee and ankle.

The roentgenologic manifestations of fracture are: loss of continuity of normal bone contour, distortion of trabecular pat-

tern, angulation of the longitudinal axis of a bone shaft, separation of bone fragments and over-riding or impaction of fragments. Both over-riding and impaction appear as areas of increased density at the fracture site, but they can be differentiated by the fact that there is little or no lateral displacement of fragments in impaction, whereas such displacement is necessarily present in over-riding. Fracture lines may be transverse, oblique or spiral, single or multiple. In children an incomplete greenstick type of break is relatively common. Incomplete fractures in adults are usually the result of sustained or repeated stresses rather than a single injury. The best known example is the "march fracture" of a metatarsal, so-called because it commonly occurs among soldiers during forced marches. Such fractures may not be visible at the time of initial roentgenographic examination and may be recognized only after formation of callus at the site of the incomplete break.

Fractures that extend into the articular surfaces of weight-bearing joints, such as the knee and ankle, always call for a guarded prognosis, because they are apt to precipitate the development of traumatic arthritis. This is particularly true if anatomic reduction cannot be accomplished.

An uncomplicated fracture of recent origin will show a sharply defined fracture line, normal regional bone density and associated soft tissue swelling. Within two or three weeks the fracture line will have become hazy, regional osteoporosis will be evident and soft tissue swelling will have largely subsided. Ossified callus can usually be seen around the fracture within one to four weeks, depending on the age and general condition of the patient and on the site of injury. Callus is never seen in joint capsules (e.g., femoral neck fractures) and is seldom observed following fractures of the innominate bone, although the latter almost invariably unite.

The only convincing roentgenologic proof of solid union of a fractured bone is evidence of bony trabeculae extending across the fracture line. It should be remembered that fibrous union and unossified callus are not recognizable on films, and thus clinical evidence may precede roentgenologic signs by several weeks.

Signs of nonunion or delayed union are: persistence of a fracture line beyond the time usually expected for its disappearance, excessive widening of the fracture line due to bone absorption, increased density and rounding-off of opposing fragment ends and absence of callus formation. In certain instances roentgenograms exposed in alternate abduction and adduction of the extremity will show abnormal mobility at the fracture site.

Acute traumatic dislocations may occur in the shoulder, elbow, wrist and hip joints. Frequently subcoracoid dislocation of the shoulder is associated with a fracture of the lip of the glenoid fossa. Anterior dislocation of the radial head may accompany a fracture of the ulna. Anterior displacement of the carpal lunate occasionally occurs in conjunction with a fracture of the carpal navicular. In the lower extremity, posterior dislocation of the femoral head is usually the result of a break in the posterior wall of the acetabulum. Congenital dislocation of the hip is recognized by the high position of the femur in relation to a poorly developed, shallow acetabulum.

Fractures which extend into open epiphyseal lines may result in displacement of the entire epiphysis. If subsequent reduction is complete, serious interference with normal bone growth seldom follows. Medial and posterior slipping of the capital femoral epiphysis without apparent fracture occurs at times in overweight adolescent boys.

Periosteal contusions and metaphyseal infractions in infants and young children may occur as the result of surprisingly minor trauma and may produce a startling roentgenographic appearance due to exuberant callus formation and extremely rapid ossification of subperiosteal hemorrhages. Because a history of trauma is often withheld or otherwise obscured, a diagnosis of some bizarre skeletal disease may be erroneously postulated. Unrecognized skeletal trauma of this sort, which only recently has been fully appreciated, is one of the most important skeletal disorders in pediatric radiology.

In the presence of certain underlying bone diseases, notably fibrocystic disease and neoplasms, bone cortex may be thinned to such an extent that a fracture occurs spontaneously or as the result of slight trauma (Plate 36, p. 141). These so-called "patho-

PLATE 32.—Fractures before and after treatment.

logic" fractures frequently heal surprisingly well; furthermore, if a cyst is the causative factor, it too may heal following the break. Unfortunately, growth of neoplastic lesions is not similarly affected.

Following open reduction of a fracture, fixation of the fragments by metallic screws, nails or plates may be necessary. These objects show up roentgenographically as shadows of extreme density. Bone grafts also can be recognized, although they cast shadows which are no denser than other bone.

Views A_1 and A_2 of Plate 32 illustrate in anteroposterior and lateral projections a typical fracture of the distal portion of the right radius with associated avulsion of the styloid process of the right ulna. The fracture, which resulted from the patient's falling on his outstretched arm, has produced posterior tilting of the distal radial fragment. A_3 and A_4 show improved alignment of fracture fragments after manipulative reduction.

Plate 32, *B,* illustrates a fracture of the right femoral neck before and after insertion of a metallic Smith-Petersen nail.

When the fractures of the left tibia and fibula shown in C_1 and C_2 failed to unite in the time usually required for healing, open reduction was done. The opposing ends of the fracture fragments were freshened and bone grafts were placed across the fracture site (C_3 and C_4). Metallic screws hold the grafts.

ASEPTIC NECROSIS (OSTEOCHONDRITIS). Under this heading may be grouped a number of localized bone disorders that present similar roentgenologic findings but differ in anatomic location. Unfortunately, the lesion at each of the various sites of involvement frequently is designated by the name of the man who described the condition in that particular location, and the resulting variety of names suggests that we are dealing with entirely different diseases. However, it is now generally agreed that a similar pathologic process, viz., temporary local ischemia, is common to all. In most instances the disease is self-limiting, and revascularization takes place by ingrowth of blood vessels from adjacent healthy tissue. The etiology is indeterminate, although there is considerable evidence to support trauma as the causative agent.

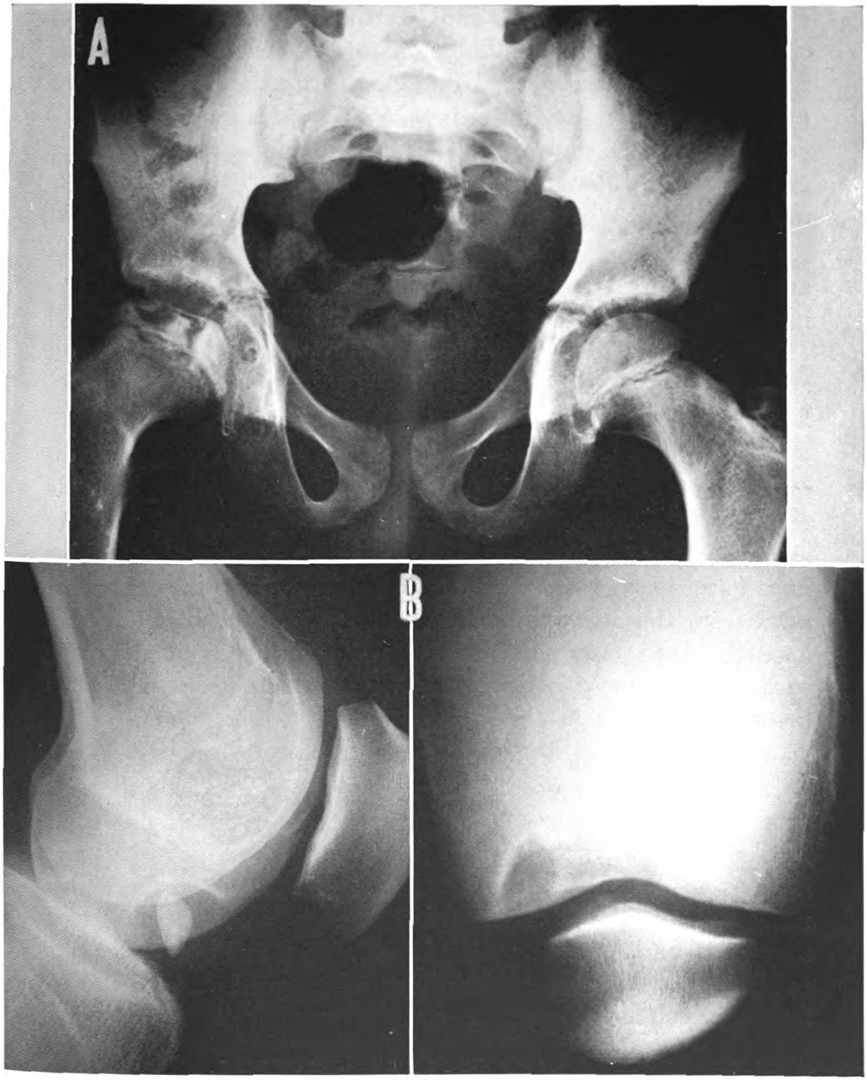


PLATE 33.—*A,* osteochondritis (Perthes' disease), right hip. *B,* osteochondritis dissecans, left knee.

Aseptic necrosis of the hip (Perthes' disease) is a lesion of clinical significance and differs in this respect from the many nonsymptom-producing forms of the disease. In Perthes' disease (Plate 33, *A*) the capital femoral epiphysis is flattened, broadened, fragmented and increased in density. The femoral neck is customarily broadened and shortened. Usually the acetabulum is not involved and the hip joint space is preserved.

Other common skeletal sites of adolescent aseptic necrosis are the tibial tubercle (Osgood-Schlatter disease); the tarsal navicular (Köhler's disease); the second or third metatarsal head (Freiberg's disease); the calcaneal epiphysis (Sever's disease), and the secondary ossification center in the patella (Sinding-Larsen disease).

Localized, aseptic necrosing lesions in adults are not uncommon, and the roentgenographic signs they produce are fairly characteristic. Osteochondritis dissecans conceivably may involve any articular surface, but it is typically associated with the knee joint. Perhaps from trauma, a small fragment of bone separates from the articular surface of the medial femoral condyle, loses its blood supply and acts as a foreign body. Identification of the dense, loose body in the joint and of the defect in the bone from which it arises constitutes a pathognomonic roentgenographic picture, illustrated in Plate 33, *B*.

Aseptic necrosis of the carpal lunate (Kienböck's disease) produces decrease in size and increase in density of this bone. It is almost always the result of trauma. Aseptic necrosis is also seen as an occasional complication in fractures of the carpal navicular, the femoral head and the astragalus. Caisson workers may develop aseptic necrosis of the femoral and humeral heads in addition to multiple bone infarcts which produce a characteristic roentgenologic appearance.

NONSPECIFIC INFECTIOUS LESIONS. The word osteomyelitis means inflammatory disease of the bone marrow. Actually, the classic variety of nonspecific osteomyelitis is a panosteitis which involves not only the medullary cavity but also the cortex and the periosteum. The infectious agent, usually staphylococcus, spreads hematogenously and is carried to the

metaphysis of a long bone via the nutrient artery. A localized abscess is formed in the spongiosa of the medullary cavity; and if the process is not recognized promptly and arrested by suitable antimicrobial drugs, it soon spreads through the haversian system of the cortex to the periosteum, where a subperiosteal abscess develops. For the first week or 10 days of this type of bone infection, roentgenograms are negative for evidence of osseous abnormality (Plate 34, A_1). Aside from unpredictable soft tissue changes, the earliest roentgenographic manifestation of the disease is patchy bone destruction of the spongiosa in the metaphysis (Plate 34, A_2). Subperiosteal repair is stimulated by the adjacent abscess beneath the periosteum, and the envelope of new bone which is laid down around the cortex at the site of infection is known as involucrum (white arrows in A_3). Involucrum first appears on the roentgenogram as a thin streak of increased density that parallels the shaft of the bone; but later it becomes a relatively thick, dense, osseous cloak which eventually forms a new shaft.

Meanwhile, the destructive phase of the disease continues, and abscesses within the marrow cavity enlarge and coalesce. Elevation of the periosteum by abscess formation deprives the cortex of its main blood supply, and the dense, cortical bone undergoes necrosis, breaking up into a number of fragments called sequestra (black arrows in A_3). Some of these sequestra are extruded through the shell of newly formed involucrum via openings known as cloaca; others are so large that they remain in situ and require surgical removal. In A_4 is shown a large operative defect in the upper midportion of the tibia two years after removal of infected bone.

With well-managed surgical treatment, reinforced by the use of antibiotic drugs and guided step by step by serial x-ray examinations, it can be expected that an osteomyelitic process which has progressed even to the degree shown in this instance will subside and that the involved bone will gradually assume a more normal appearance. Permanent scarring in the form of dis-

torted trabecular pattern and thickened sclerotic cortex follows healing of the lesion (Plate 34, A_4).

In some instances, nonspecific osteomyelitis takes the form of a localized, low-grade destructive lesion known as Brodie's abscess. Occasionally, the cortex becomes thickened by a diffuse, proliferative process that simulates neoplasm or syphilis.

SPECIFIC INFECTIOUS LESIONS. Congenital syphilis, now uncommon, is of considerable historical interest as a type of bone infection in infancy. It is well worth continued attention if for no other reason than to demonstrate how a specific chronic granulomatous process can produce skeletal alterations which are reflected in roentgenograms in a striking and characteristic manner. Spirochetes, transmitted to the offspring by an infected mother, lodge at multiple sites within the skeleton, where they produce osteochondritis, osteomyelitis and periostitis (Plate 34, *B*, *C*). Irregularity of the growing ends of the metaphyses and widely scattered lesions in the shafts which show both destructive and proliferative bone changes represent the most important and distinctive roentgenographic signs of congenital syphilis. Periosteal new bone formation, also a prominent feature of the disease, is encountered so commonly in other infantile diseases that it can be considered characteristic of congenital syphilis only when found to the extent shown in *D*.

Complete healing of the bone lesions, with or without specific therapeutic measures, is characteristic of congenital syphilis. Occasionally, latent syphilitic infection becomes active in later childhood in the form of dense periosteal thickening, most commonly encountered along the anterior aspects of the tibias. The classic stigma of congenital syphilis, saber shin, is dependent on this feature of the disease.

Bone lesions in acquired syphilis are uncommon. A mosslike type of periostitis is the most frequent roentgenographic finding in this disease, although occasionally cortical and cancellous bone is involved in a dense, sclerotic osteitis.

Tuberculous osteomyelitis is uncommon at all ages, compared with the far more important joint lesions of tuberculosis. Blas-

PLATE 34.—*A*, stages of chronic nonspecific osteomyelitis. *B–D*, long bones of three patients with congenital syphilis.

tomycosis, actinomycosis and yaws are other specific infections which rarely involve the long bones.

ARTHRITIS. The articular surfaces of the bones which comprise a diarthrodial joint are capped by varying thicknesses of articular cartilages which are relatively radiolucent and appear on roentgenograms of a joint as a "space" between opposing bone ends. The synovial membrane, which is in reality the lining of the joint capsule, extends only to the periphery of the articular cartilages. It has approximately the same density as cartilage and surrounding soft tissues and, therefore, cannot be differentiated roentgenographically. Because most types of arthritis consist of either proliferative or degenerative changes in the intra-articular and periarticular structures which are not directly visible, the roentgen diagnosis of inflammatory joint disease must be made on the basis of indirect signs or from evidence of secondary involvement of juxta-articular bone. It is not surprising, then, that the clinical signs of all types of arthritis precede roentgenographic changes by weeks or months.

Rheumatoid arthritis is a migratory polyarthritis in which roentgenographic signs ordinarily are seen earliest and to best advantage in the wrists and proximal interphalangeal joints of the hands. For many months one may see nothing more than fusiform soft tissue swelling around the involved joints and diffuse osteoporosis in juxta-articular bone. Later there is gradual reduction of the joint spaces, followed by subarticular bone destruction, subluxation and irreversible deformities (Plate 35, *A*).

Osteoarthritis is primarily a degenerative disease of older persons, apparently associated with the aging process. The articular cartilages appear to wear out, osteophytes are formed and opposing bone surfaces become sclerotic and irregular. In the knees, where osteoarthritic changes are most common, intra-articular effusion can be recognized roentgenographically (Plate 35, *B*). When the hands are involved, the distal interphalangeal joints are the sites of the most pronounced changes, an aid in the differentiation of osteoarthritis from rheumatoid arthritis.

Coxa malum senilis is a particular form of degenerative arthritis in which reduction of the hip joint space is associated

PLATE 35.—*A*, rheumatoid arthritis. *B*, osteoarthritis. *C*, tuberculosis. *D*, gout.

with sclerosis, marginal spurring and areas of cystlike subcortical destruction in the femoral head and acetabulum. It is seen most commonly in the aged, but not infrequently it occurs in young adults who have had chronic hip disease in childhood. Degenerative changes classified as traumatic arthritis are occasionally encountered, at any age, following intra-articular fracture or other joint injury.

Infectious arthritis may be due to any one of a number of different etiologic agents, among which are the tubercle bacillus, staphylococcus, streptococcus and gonococcus. Any joint or combination of joints may be invaded by these various organisms, but a single, weight-bearing articulation is the usual site of involvement. In general, the roentgenographic signs of infectious arthritis consist of early haziness of joint margins due to periarticular soft tissue swelling and accumulation of exudate within the capsule; reduction in joint space due to destruction of cartilage; regional decalcification followed by actual destruction of subchondral bone, and subsequent ankylosis of opposing bone ends.

Frequently, the various types of infectious arthritis are not distinguishable on the basis of roentgen findings alone. The sequence of appearance of these signs, however, may be of considerable diagnostic value. For example, in pyogenic infections the involved joint-space is reduced early in the disease and bone destruction is first observed on the weight-bearing aspect of the joint's articular surface. In tuberculous arthritis, on the other hand, reduction of the cartilage space is a late manifestation and noncontact portions of the joint characteristically show the earliest foci of destruction. Tuberculous joints are apt to show a fairly characteristic scalloped type of destruction in adjacent bone such as that seen in the left acetabulum in Plate 35, *C*. Certain other distinctive localized roentgenographic signs, such as "kissing sequestra" in tuberculosis of the knee, also are of some value in the differentiation of various types of joint infection, but in general they are much less important than careful bacteriologic study of aspirated joint exudate.

The x-ray findings in gout may closely simulate those of mixed rheumatoid arthritis and osteoarthritis. Although tangible roent-

genographic evidence of this disease is commonly associated with the feet (Plate 35, *D*), bones adjacent to numerous other joints may show the same intramedullary and extramedullary destructive changes due to adjacent tophi.

Intra-articular hemorrhage associated with hemophilia eventually produces arthritis, which in the knee or ankle of the adolescent child is fairly characteristic. Roentgenograms show the epiphyses of the involved joint to be hypertrophied, flattened and irregular. The recurrent hemarthrosis also produces patchy calcification and increased prominence of periarticular soft tissue shadows.

NEOPLASTIC LESIONS. Up to a point, tumors which involve bone can be studied profitably by x-ray methods. Early in the course of its development a tumor growing in bone produces destructive or proliferative osseous changes which can scarcely be overlooked by a careful observer of films. In roentgenograms, neoplastic lesions are nearly always recognizable as such, regardless of size or of the manner in which skeletal anatomy has been altered. Often the roentgenologist can differentiate with accuracy between benign and malignant tumors of bone, a diagnostic contribution of major importance. However earnestly he may desire to analyze the situation in even greater detail—to specify the exact cell type of a malignant bone tumor—he must realize that the microscopic characteristics are by no means accurately reflected in gross appearances, whether these are observed in the pathology laboratory or in the x-ray viewing room. Accurate histologic identification of tissue obtained through biopsy is the only reliable method of determining exact tumor type, and this procedure is indicated whenever malignancy is suspected. It is no more than fair to point out that even the most skilled tissue pathologist will, on occasion, be unable to make an exact diagnosis.

The roentgenologist and the pathologist should co-operate with no slightest feeling of rivalry, because each is capable of enhancing the diagnostic value of the other's efforts. X-ray examination is most effective in discovering bone lesions, in determining their extent and in identifying those which are neoplastic.

From information so obtained, the most desirable site for biopsy can best be determined, and occasionally a shrewd guess can be offered with regard to the tumor type. Histologic examination is vitally important in deciding on the best course of treatment and in prognosticating the outcome.

Any classification of bone neoplasms is subject to criticism because of the diversity of opinion among authorities regarding the origin of a number of these lesions and because of the confusion which still exists in the nomenclature. It seems desirable for our purpose to limit the presentation of roentgenographic findings to the more common tumors.

Benign tumors, in general, are observed as relatively small, localized and well-circumscribed areas of altered bone density and contour. They made erode and expand adjacent normal bone but do *not* actively destroy it.

Osteochondroma usually presents itself as a stalklike exostosis of relatively normal bone which extends outward from the metaphysis of a long bone along the plane of tendinous attachments. Usually the tumor is capped by a tuft of radiolucent cartilage within which islands of calcification may develop (Plate 36, *A*). At times, osteochondromas are sessile rather than pedunculated. Rarely, they are multiple and hereditary.

Enchondromas are purely cartilaginous tumors which appear as smoothly rounded zones of diminished density fully surrounded by bone. They occur most commonly in the metacarpals and phalanges.

The histology of giant cell tumor is the subject of considerable dispute. Giant cell tumor is most commonly found in young adults and is particularly apt to arise in the lower end of the radius, the lower end of the femur or the upper end of the tibia. It develops within the medullary cavity but seldom is seen roentgenographically until it has eroded and expanded the overlying cortex (see Plate 104, *A*, p. 404). The tumor is visible as a zone of decreased density within which narrow osseous trabeculae may or may not be evident.

Osteoid osteoma, chondroblastoma, nonosteogenic fibroma, hemangioma and xanthoma are other significant benign tumors.

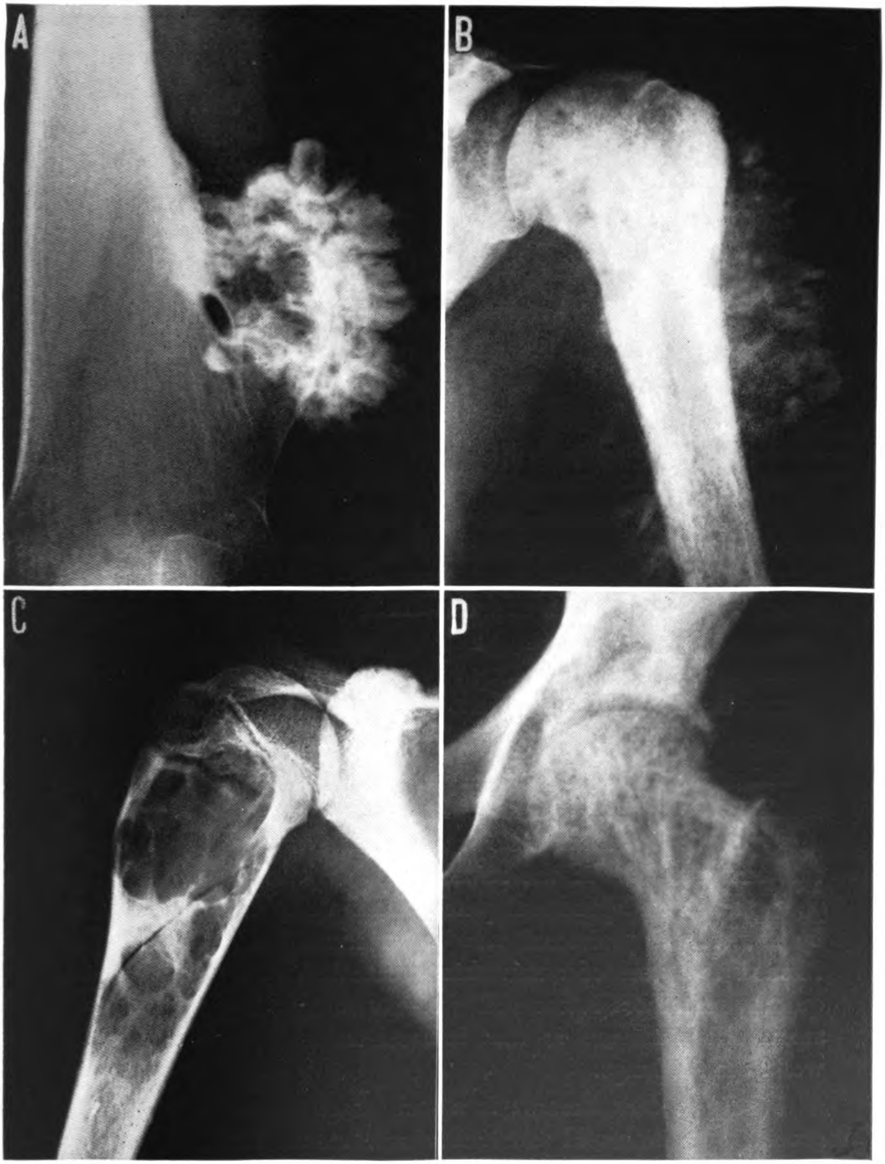


PLATE 36.—*A*, osteochondroma. *B*, osteogenic sarcoma. *C*, bone cyst with "pathologic fracture." *D*, Paget's disease.

Primary malignant tumors of bone are relatively rare. About 1 per cent of all malignant neoplasms arise in bone. The outstanding roentgenologic features which these lesions have in common are: (1) early and extensive bone destruction, denoting rapidity of growth; (2) absence of a clearly defined line of demarcation between neoplastic tissue and normal bone; (3) early rupture of the cortex, and (4) extensive invasion of surrounding soft tissues. The character and amount of bone proliferation vary with the type of neoplasm. Metastases to the lung are to be expected in all types except multiple myeloma.

Osteogenic sarcoma is most frequently observed in children and young adults. Although any bone may be involved, the metaphysis of a humerus, femur or tibia is the favorite location of this highly malignant neoplasm. A number of different types of osteogenic sarcoma have been described, but no attempt at subclassification will be made here. Suffice it to say that the tumors may be predominantly osteolytic or osteoblastic. They manifest the general roentgenographic signs mentioned above. Much has been written about the spectacular, but rather inconstant and unreliable, "sunburst" appearance in osteogenic sarcoma. This occasional finding is caused by countless spicules of "tumor bone" radiating out into soft tissues perpendicular to the long axis of an involved bone (Plate 36, *B*).

Ewing's tumor (endothelial myeloma) is another neoplasm much disputed from the histologic point of view, and its roentgenographic appearance shows remarkable variability. Typically, this tumor occurs in the midshaft region of a long bone in a young adult and produces patchy bone destruction surrounded by lamellated periosteal new bone formation that has been likened to layers of onion skin (Plate 105, *A*, p. 406). It frequently resembles osteomyelitis roentgenologically and is unique among bone tumors in that it metastasizes to other bones as well as to the lungs.

Periosteal fibrosarcoma is a rare lesion characterized by its eccentric position and soft tissue involvement, which frequently is out of all proportion to its osseous manifestations.

Multiple myeloma has been discussed in relation to the skull

and spine. Rarely, a solitary myeloma is found in an arm or leg bone or in one of the pelvic bones (Plate 104, *C*, p. 404).

Other rare primary bone tumors are hemangiosarcoma and lymphoblastoma. Leukemia in children often produces widespread foci of bone destruction in all parts of the skeleton, notably the metaphyses of the tubular bones. Subperiosteal leukemic infiltration may stimulate lamellated new bone formation.

Metastatic neoplasm may be either osteolytic or osteoblastic. Osteolytic metastases occasionally develop from carcinoma of the breast, thyroid, lung and kidney; they rarely arise from other primary carcinomas. As in the skull and spine, osteoblastic metastases in the extremities are most commonly derived from carcinoma of the prostate. Primary Ewing's tumor of bone is to be remembered as a possible source of either type.

In practically all cases in which malignant neoplasms metastasize to the skeleton, multiple bones are involved with no evidence of extension to surrounding soft tissues. Metastatic lesions seldom develop distal to the elbows and knees, although one notable exception is metastatic neuroblastoma in children. This neoplasm frequently involves even the bones of the hands and feet as well as other parts of the skeleton. Its roentgen appearance is similar to that of leukemic bone involvement.

Miscellaneous Lesions

LOCALIZED CONGENITAL MALFORMATIONS. Significant congenital defects in the bones of the extremities are most commonly due to abnormal segmentation in the hands and feet, in which either more or less than the usual number of bones are present. In the arms and legs, an entire long bone or a portion of that bone may occasionally fail to develop.

Congenital clubfoot, a loosely used term that usually means talipes equinovarus deformity, is a primary soft tissue defect producing adduction, inversion and plantar flexion of the bones of the foot. Special roentgenographic technic designed particularly for this entity is invaluable when used to confirm the diagnosis and to observe periodically the results of treatment.

GENERALIZED SKELETAL DYSTROPHIES. Dysostosis cleidocranialis, osteogenesis imperfecta, achondroplasia and dysostosis multiplex have been briefly considered in Chapter 3 because their manifestations in the skull bones are so striking. It should be emphasized, however, that roentgenographic findings in the extremities of these patients may be even more important from the standpoint of accurate diagnosis.

The term dyschondroplasia is an unsatisfactory one commonly used to describe a wide variety of other generalized developmental faults in the normal orderly change of cartilage into bone. Dyschondroplasia is characterized roentgenographically by bizarre changes in contour and in density of the ends of the tubular bones.

The spotty bones of osteopoikilosis and the chalky bones of osteopetrosis, both of which were mentioned in connection with the spine, also manifest their typical roentgenographic signs in the pectoral girdles, the pelvis and the extremities.

Fibrocystic disease (osteitis fibrosa cystica) includes several types of fibrous dysplasia in bone which are apparently produced by different etiologic factors but have a more or less similar roentgenologic appearance. The simplest and commonest manifestation is the solitary bone cyst which is almost always found in the proximal metaphysis of either the humerus or the femur of a growing child. The typical cyst is seen as a well-demarcated, elongated, oval area of decreased density which expands and thins the cortex from within. Plate 36, *C*, illustrates such a lesion in the right humerus of a 12 year old boy. A so-called "pathologic fracture" can be seen extending obliquely through the cyst.

Hyperparathyroidism, basically an endocrine disorder, warrants mention here because it frequently is associated with multiple bone cysts in the tubular and flat bones accompanied by generalized skeletal demineralization of an extreme degree. After extirpation of the offending parathyroid adenoma, rapid regression of the cysts and recalcification throughout the skeleton can be observed in serial roentgenograms.

Several variations of polyostotic fibrous dysplasia not associated with parathyroid disease have been described. The cyst-like lesions seen roentgenographically in the bones of these

patients are not true cysts but contain solid masses of rubbery fibrous tissue. Generalized demineralization is notably absent.

PAGET'S DISEASE. In addition to the pelvis, spine and skull, which are the sites of particular predilection, osteitis deformans may on occasion involve the femur, the tibia and the humerus. Characteristically, the disease produces enlargement, cortical thickening and widespread coarsening of trabeculae when long bones are affected. Bowing of bone shafts is common and sometimes marked. Plate 38, *D,* shows advanced Paget's disease in the femur of a 56 year old man.

VITAMIN DEFICIENCY DISEASE. Infantile rickets, due to lack of vitamin D and sunlight, consists essentially of inadequate calcification of osteoid tissue. Although there is pronounced generalized rarefaction of bone with increased prominence of trabeculae, the most striking roentgenographic changes are found at the distal metaphyseal ends of the rapidly growing long bones. Owing to faulty lime salt deposition, the space between the adjacent metaphysis and epiphysis is increased, and that portion of the metaphysis which contains sufficient calcium to cast an x-ray shadow has a stringy, frayed appearance (Plate 37, *A*). The ends of the bones may be abnormally flared and cupped. During the healing phase x-ray examination shows recalcification of the metaphyses and epiphyses and extensive subperiosteal new bone formation.

The roentgenologic changes in the various types of endogenous rickets (renal rickets, celiac rickets, vitamin D resistant rickets, etc.) are similar to those in the infantile vitamin deficiency type.

In scurvy, due to vitamin C deficiency, the fundamental fault is the development of an unstable framework of osteoid within which calcification goes on unhindered. The poor quality bone thus formed gives rise to characteristic roentgenographic changes best seen in the tubular bones at the knees. Piled-up lime salt at the zone of provisional calcification in the metaphyseal end of a long bone produces an irregular band of increased density. This band and generalized osteoporosis constitute the earliest roentgen signs of scurvy.

Osteoporosis is striking in well-advanced cases that involve cortical as well as trabecular bone. Residual calcium deposits in the outermost layer of epiphyseal ossification centers stand out prominently against a background of extensively demineralized bone. These delicate annular shadows, known as Wimberger's rings, are characteristically associated with infantile scurvy. In the metaphyses immediately adjacent to the zone of provisional calcification a narrow transverse band of decalcified bone can be recognized in films. This is called the "scurvy line." Within this zone minute fractures, too small to be recognized individually, occur as the weakened bone is compressed by the pull of skeletal muscles. Provisional bone, clogged with retained calcium, contrasts sharply with the scurvy line in films. Lateral displacement of the fragmented and largely decalcified bone (lateral spurring) can be seen at the margins of the scurvy line—an important sign of the disease. The shadows of calcified subperiosteal hemorrhages are even more characteristic, but these are never demonstrable until healing has begun and, therefore, are not helpful in the recognition of early cases. All of the deviations from the normal are illustrated in Plate 37, *B*, and *C*.

Both rickets and scurvy produce flaring and clubbing of the rapidly growing anterior rib ends, so that this sign has no differential value in roentgenologic diagnosis of these two conditions.

HYPERVITAMINOSES. It has been shown in recent years that excessive doses of either vitamin D or vitamin A may produce significant pathologic changes which are roentgenologically demonstrable.

Hypervitaminosis D is characterized by hypercalcemia which results in generalized osteoporosis and metastatic calcification of soft tissues, especially the kidneys and periarticular tissues. It is most commonly seen in patients with rheumatoid arthritis who have received prolonged vitamin D therapy (Plate 38, *A*).

Hypervitaminosis A has been reported mainly in young children. Roentgenologically one finds cortical thickening of the tubular bones with a peculiar predilection for the metacarpals,

PLATE 37.—*A*, rickets. *B*, infantile scurvy before and after treatment. *C*, extensively calcified subperiosteal hemorrhage in another patient with scurvy.

metatarsals and ulnas. The appearance is not unlike calcified subperiosteal hemorrhages in scurvy (Plate 37, *C*).

INFANTILE CORTICAL HYPEROSTOSIS. The cortical thickenings in hypervitaminosis A are also very similar in appearance to those seen in infantile cortical hyperostosis (Caffey's disease), an important, recently described disease of infants under 6 months of age, the etiology of which has not yet been established. The almost consistent involvement of the mandible in addition to various tubular and flat bones, as well as the restricted age of onset, makes roentgenologic identification of this fascinating disorder entirely feasible. The hyperostotic mandible and long bones of a 4 month old boy with infantile cortical hyperostosis are illustrated in Plate 38, *B*, *C* and *D*.

Infantile cortical hyperostosis is but one of a host of "new" entities in the pediatric field which, for the moment, are baffling as to etiology and pathogenesis but in which roentgenologic manifestations are extremely important. Many of the diseases appear to be inborn errors of metabolism, some of which are transient, whereas others are permanently crippling or fatal.

RETICULOENDOTHELIOSES AND RELATED CONDITIONS. Chronic reticuloendotheliosis (Schüller-Christian disease) is the most important member of the group. The skull manifestations have been described in Chapter 3. Eosinophilic granuloma and Letterer-Siwe disease are related entities which produce similar areas of well-circumscribed bone destruction in the skull, vertebrae, pectoral girdles, ribs, pelvis and femora. One or several bones may be involved.

In Gaucher's disease, distinctly different osseous lesions are found. The skull is never involved; the most characteristic changes occur in the distal one third of the femur. Hyperplastic reticulum cells containing the lipoid kerasin literally pack the marrow cavities and thus produce expansion and thinning of cortex, which imparts a flasklike shape to the lower end of the bone.

CHRONIC HEMOLYTIC ANEMIAS. In Mediterranean anemia, growing tubular bones take on a characteristic rectangu-

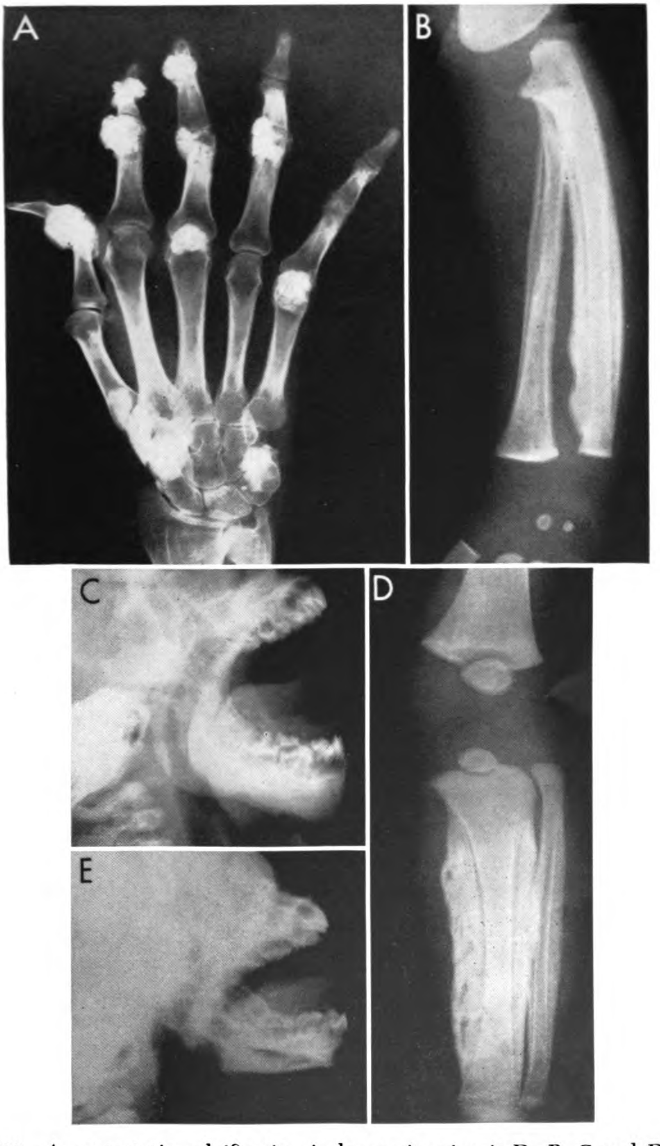


PLATE 38.—*A*, metastatic calcification in hypervitaminosis D. *B*, *C* and *D*, infantile cortical hyperostosis. *E*, normal infant mandible for comparison with *C*.

lar shape with dilatation of the marrow cavities and thinning of the corticalis. In addition, the bone shafts are traversed by a coarse, irregular network of thickened trabeculae which is particularly prominent against the background of atrophic bone. Bone age usually is retarded.

Sickle cell anemia and chronic hemolytic jaundice rarely produce similar changes in the extremities.

ENDOCRINE DISEASES. A number of endocrine diseases of infancy and childhood produce alteration in the normal time schedule of epiphyseal ossification. The most striking example is found in the great delay characteristic of cretinism. Compare the extent of carpal ossification in the 3 year old cretin illustrated by Plate 39, *A*, with the normal in *B*. In addition to their value in the diagnosis of severe hypothyroidism, roentgenograms of the hands and feet are helpful in determining the result of treatment. Response to thyroid medication is dramatically shown when films made before and during treatment are compared. Mongolian idiocy is not an endocrine disorder, but it is sometimes mistaken for cretinism. An isolated but fascinating roentgenographic finding in mongolism is the congenital shortening of the middle phalanx of the fifth finger, which occurs in almost 75 per cent of cases.

In acromegaly the hands are large, broad and spadelike with pronounced overgrowth of the distal phalangeal tufts and prominence of bony protuberances along the phalangeal shafts. Both metacarpal and phalangeal shafts appear narrow in relation to the bulbous ends of these bones (Plate 39, *C*). Roentgenograms of the feet show changes similar to those in the hands. The entire skeletal structure has a massive appearance and the joints frequently show signs of osteoarthritis.

TROPHIC LESIONS. Disruption of sensory pathways by the lesions of tabes dorsalis and syringomyelia deprives patients of the warning pain which serves so effectively to protect joints from undue trauma. In patients with these diseases it is not unusual to find one or more "Charcot joints," articulations which have become badly disorganized as the result of oft-repeated injury. The typical x-ray findings are eburnation, proliferation,

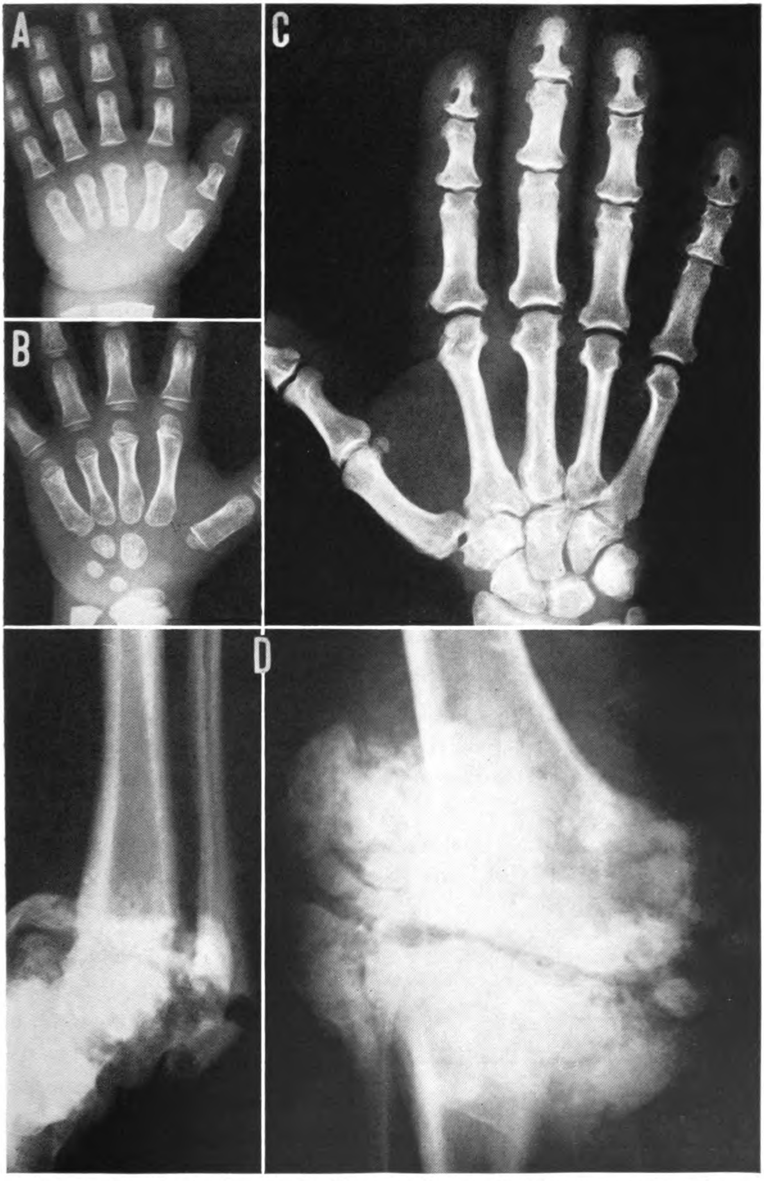


PLATE 39.—*A,* cretin, age 3. *B,* normal, age 3. *C,* acromegaly. *D,* neurotrophic arthropathy.

fragmentation and subluxation of bone ends associated with swelling of soft parts. Such joints are painless, despite the serious damage which they have sustained. In tabes the joints of the legs are most commonly involved by these neurotrophic lesions, whereas in syringomyelia upper extremity involvement is the rule. Plate 39, *D*, illustrates the typical changes of Charcot's arthropathy of the left knee and ankle of a 55 year old man with tabes dorsalis.

Roentgenograms of the hands or feet may reflect the presence of leprosy, Raynaud's disease, erythromelalgia, thromboangiitis obliterans, arteriosclerosis and scleroderma. The x-ray sign common to all these conditions is spontaneous amputation of portions of the phalanges or, perhaps, of the entirety of one or more of these bones.

PULMONARY OSTEOARTHROPATHY. The presence of certain chronic pulmonary or mediastinal diseases may reasonably be suspected when clubbing of the fingers is observed. In addition, roentgenograms of the tubular bones may show periosteal proliferation along the shafts of the bones, the so-called hypertrophic form of pulmonary osteoarthropathy. The cause of this remote expression of chest disease is unknown, but its diagnostic importance cannot be minimized. It develops with surprising rapidity in patients with bronchogenic carcinoma. In our experience it is not apt to be associated with pulmonary tuberculosis. The periosteal new bone abruptly disappears when the pulmonary lesion is eradicated. Plate 40, *A*, shows pulmonary osteoarthropathy of the femur associated with a small bronchial carcinoma of the right upper lobe. The osseous changes regressed following pneumonectomy.

SARCOIDOSIS (BOECK'S SARCOID). This condition is given a separate heading because its suggested relationship to the tubercle bacillus has never been adequately proved. The disease commonly involves skin, lymph nodes and lungs and occasionally produces ocular and osseous lesions. Inasmuch as the pulmonary manifestations of sarcoid are not entirely diagnostic, the finding of bone lesions may help clarify an otherwise obscure chest condition. The most characteristic bone changes are to be

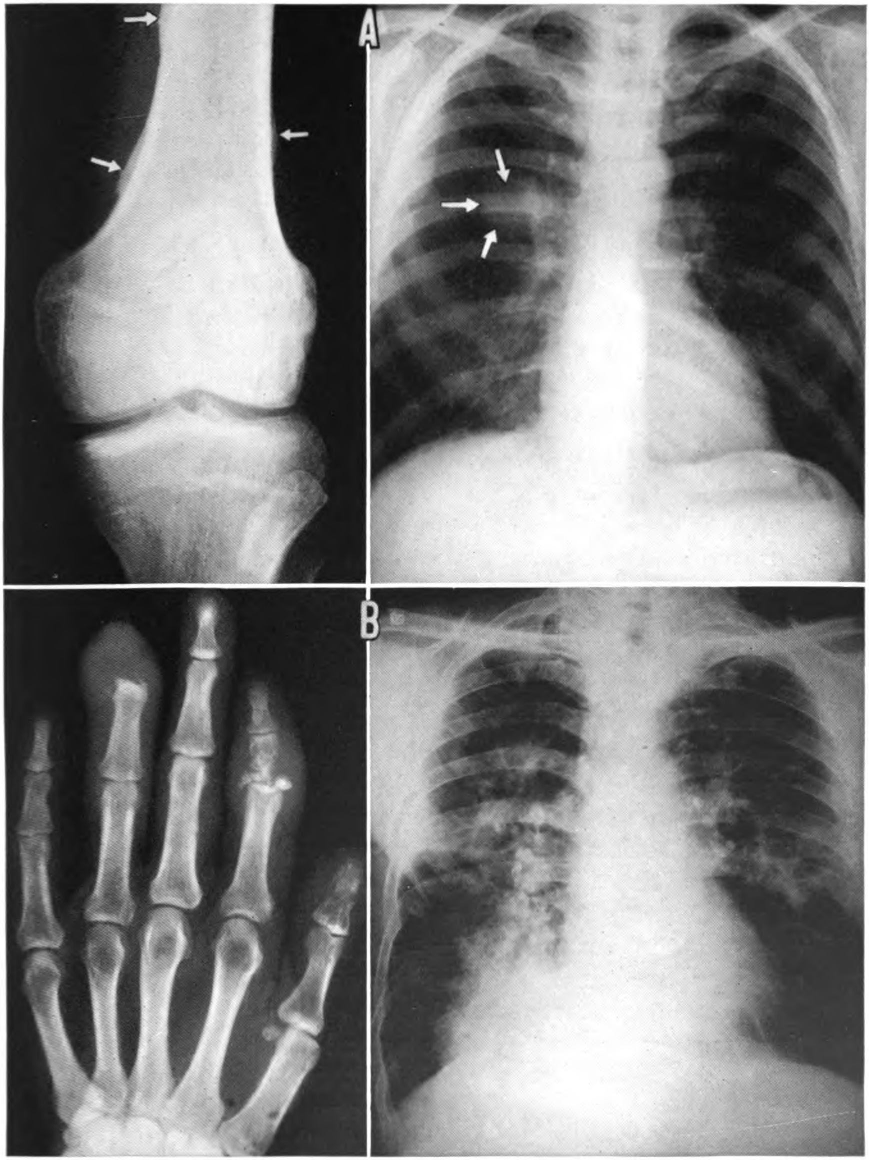


PLATE 40.—*A,* hypertrophic pulmonary osteoarthropathy (*left*) due to early bronchogenic carcinoma (*right*). *B,* osseous and pulmonary sarcoidosis.

found in the hands and feet, where one occasionally sees small, central, cystlike zones of destruction in the ends of the metacarpals, metatarsals and phalanges. More often, the lesions begin as a coarsening of the trabecular pattern, followed by localized destruction of cortical and central bone. Osseous and pulmonary manifestations of a proved case of sarcoidosis are illustrated in Plate 40, *B*.

NEUROFIBROMATOSIS. Various and inadequately explained skeletal abnormalities are observed with great frequency in patients with multiple neurofibromas in soft tissues. Regional overdevelopment or underdevelopment of bone, subperiosteal blebs, central zones of destruction, pseudarthroses and scoliosis are some of the more common findings.

SOFT TISSUE ABNORMALITIES. Roentgenographic recognition of lesions in the extremities is not limited to those which involve the osseous structures. Judicious use of lightly exposed roentgenograms frequently enables one to recognize significant deviations from the normal appearance of soft tissues. Recognizable calcification within muscle bundles and fascial planes (myositis ossificans) may follow trauma (Plate 41, *A*). In association with scleroderma and certain other skin diseases similar changes are known as calcinosis. Calcification in the insertion of the supraspinatus tendon (*B*) is a common roentgenographic finding in patients with severe pain and tenderness over the acromion process. Ligamentous calcification may be found on the inner aspect of the knee and adjacent to various portions of the bony pelvis. Lime salt deposits may also occur in sclerotic arteries and thrombosed veins and around intramuscular parasites. Some neoplasms—notably hemangiomas, synovial osteochondromas and malignant synoviomas—contain lime salt.

With a single exception, all forms of normal soft tissue have the approximate density of water and are, therefore, equally radiolucent and indistinguishable from one another in roentgenograms. Adipose tissue, owing to its considerably lesser density, is shown in fairly sharp contrast with other, more radiopaque, soft tissues. This contrast permits the diagnosis of lipoma on the basis of x-ray findings alone. For example, observe the rela-

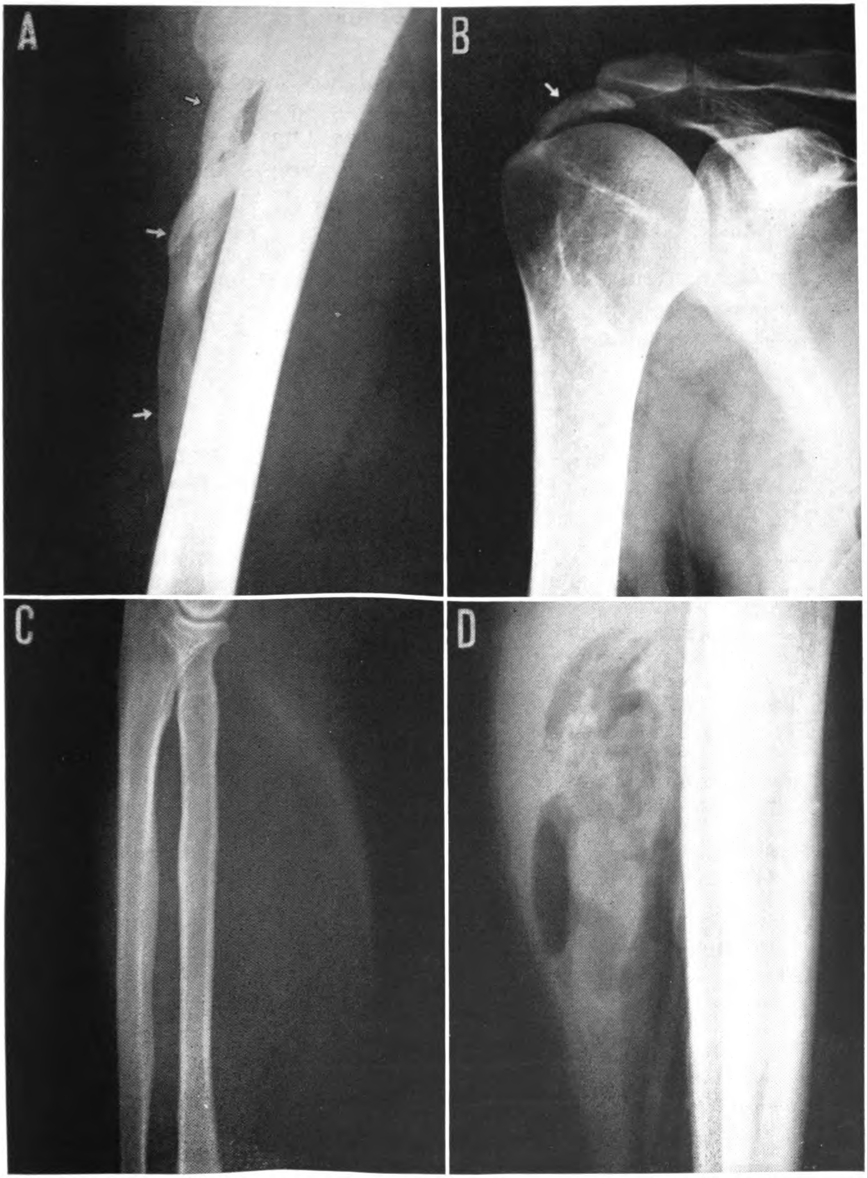


PLATE 41.—*A*, traumatic myositis ossificans. *B*, calcified supraspinatus tendon. *C*, lipoma. *D*, gas gangrene.

tive radiolucency of the large fatty tumor on the ventral aspect of the right forearm in Plate 41, *C*.

Collections of gas formed in soft tissues by anaerobic bacteria such as Bacillus welchii are clearly visible on roentgenograms as areas of increased radiolucency (Plate 41, *D*). Air is sometimes introduced into the soft tissues at operation or as the result of trauma and one must be careful to avoid the mistake of assuming that air bubbles are evidence of gas bacillus infection. Air is usually absorbed rapidly, whereas the bubbles produced by gas-forming organisms become progressively more abundant unless the infection is brought under control.

READING LIST

ALBRIGHT, R., AND REIFENSTEIN, E. C.: *The Parathyroid Glands and Metabolic Bone Disease* (Baltimore: Williams & Wilkins Company, 1948).

CAFFEY, J.: *Pediatric X-ray Diagnosis* (3d ed.; Chicago: Year Book Publishers, Inc., 1956).

——: Chronic poisoning due to excess of vitamin A: Description of clinical and roentgen manifestations in seven infants and young children, Pediatrics 5:672–688, April 1950.

——, AND SILVERMAN, W. A.: Infantile cortical hyperostoses: Preliminary report on a new syndrome, Am. J. Roentgenol. 54:1–16, July, 1945.

CAMP, J. D.: Contrast myelography past and present, Radiology 54:477–506, April, 1950.

FAIRBANKS, T.: *An Atlas of General Affections of the Skeleton* (Baltimore: Williams & Wilkins Company, 1952).

GREULICH, W. W., AND PYLE, S. I.: *Radiographic Atlas of Skeletal Development of the Hand and Wrist* (Stanford, Calif.: Stanford University Press, 1950).

HODGSON, J. R.; KENNEDY, R. L. J., AND CAMP, J. D.: Reticuloendotheliosis (Hand-Schüller-Christian disease), Radiology 57:642–653, November, 1951.

HOLT, J. F., AND HODGES, F. J.: Significant skeletal irregularities of the hands, Radiology 44:23–31, January, 1945.

HOLT, J. F., AND WRIGHT, E. M.: The radiologic features of neurofibromatosis, Radiology 51:647–664, November, 1948.

LICHTENSTEIN, L.: *Bone Tumors* (St. Louis: C. V. Mosby Company, 1952).

OPPENHEIMER, A.: The diseases of the vertebral column, Am. J. Roentgenol. 53:348–369, April, 1945.

PARK, E. A.: Observations on pathology of rickets with particular reference to changes at cartilage-shaft junctions of growing bones (Harvey Lecture), Bull. New York Acad. Med. 15:495–543, August, 1939.

——; GUILD, H. G.; JACKSON, D., AND BOND, M.: Recognition of scurvy with special reference to early x-ray changes, Arch. Dis. Child. 10:265–294, August, 1935.

PHEMISTER, D. B., AND HATCHER, C. H.: Correlation of pathological and roentgenological findings in diagnosis of tuberculosis arthritis, Am. J. Roentgenol. 29:736–752, June, 1933.

PUGH, D. D.: The roentgenologic diagnosis of diseases of bones, in GOLDEN, R. (ed.): *Diagnostic Roentgenology* (Baltimore: Williams & Wilkins Company, 1952).

SANDSTROM, C.: Peritendinitis calcarea: Common disease of middle life: Its diagnosis, pathology and treatment, Am. J. Roentgenol. 40:1–21, July, 1938.

SILVERMAN, F. N.: The roentgen manifestations of unrecognized skeletal trauma in infants, Am. J. Roentgenol. 69:413–427, March, 1953.

WATSON-JONES, R.: *Fractures and Joint Injuries,* vol. 1 (4th ed.; Edinburgh & London: E. & S. Livingstone, Ltd., 1952); vol. 2 (Baltimore: Williams & Wilkens Company, 1955).

5

The Thorax

X-RAY DIAGNOSTIC methods are widely and effectively employed to evaluate the status of the thorax and of the important structures which it contains. The technical difficulties which, in the early days of medical roentgenology, made it impossible to make exposures with sufficient speed to halt cardiac and respiratory motion have been overcome. Since then, the x-ray exploration of the chest in health and disease has developed rapidly. Preparation for x-ray examination of the thorax is simple, and patients can be handled with great rapidity. The wide range of useful information regarding many structures and organs of medical importance which such examination can provide has established x-ray examination of the chest as one of the most commonly used diagnostic procedures in the practice of medicine. In the five year period, July 1, 1952, to June 30, 1957, exclusive of 157,688 survey exposures made on miniature film as part of routine patient registration, 91,689 patient-visits to the Department of Radiology at the University of Michigan have been for chest examination. This represents 33 per cent of all x-ray diagnostic procedures conducted during that time, a proportion which has remained fairly constant for more than 25 years.

With many limitations to be sure, it is possible during life to explore the thoracic walls, the diaphragm, the adjacent structures in the neck, the contents of the mediastinum and the lungs and pleura with almost the thoroughness of the anatomic laboratory

or the autopsy room. Such exploration can be conducted safely, rapidly and repeatedly with little or no discomfort to the patient. Not only the situation at any given moment but, even more important, the natural progression of disease and the response to treatment can be observed and evaluated.

Realization of the fullest benefits of x-ray diagnosis of the chest depends in great measure on the resourcefulness, the diligence and the wide clinical experience of the examiner. As in every other phase of roentgen diagnosis, medical skill is an ingredient far more important to successful performance than the electrical and mechanical instruments which must be used. By combining sound medical judgment with an appreciation of the roentgenologic appearances of familiar anatomic structures, any medical observer can utilize x-ray findings in the field of chest diagnosis to great advantage.

The intricacies presented the beginner in the translation of x-ray findings into familiar terms of normal anatomy and physiology or recognizable pathologic variations can be materially simplified. Inspection of considerable numbers of chest films prepared in surveys of large groups provides a degree of familiarity with the great variations in appearance which are to be expected among normal individuals. In no other way can such familiarity be acquired as soundly or as rapidly. The principle of mass radiography is ideally suited to the training of students because, in addition to providing study material of every conceivable type, the purpose of the survey is to screen from any particular patient-group those individuals whose chest roentgenograms prepared in standardized frontal projection show obvious or highly suspicious deviations from the expected normal. Without concerning himself for the moment with the exact nature of the observed abnormality, the untrained observer can experience the satisfying thrill of discovery by detecting roentgenographic appearances which are inconsistent with his knowledge of the normal. If he were to go no farther, acquisition of the ability to detect thoracic abnormalities, often completely unrecognizable by other methods of physical diagnosis, would constitute ample return for the effort involved. Experience gained during the chest filming of 428,543 patients on admission to

University Hospital shows that worrisome abnormalities so disclosed are to be expected in 9.1 per cent of all patients.

Going more deeply into the business of hunting down chest disease, one seeks to throw light on the exact nature of observed abnormalities. It is helpful, in breaking down the great mass of diagnostic problems which are encountered, to follow some orderly plan in analyzing chest roentgenograms. The details of one such plan have been presented in Chapter 2 (pp. 49 ff.). On recognizing that some abnormality is present, the interpreter is in a position to direct his thinking to conditions which involve primarily the chest wall and mediastinum, nontuberculous lesions of the lungs and pleura or manifest expressions of the single and commonly encountered disease, pulmonary tuberculosis. When considered according to this purely arbitrary plan of subdivision, x-ray evidences of thoracic or intrathoracic disease become less confusing and much more readily fathomed.

It is necessary to bear in mind that several disease entities may coexist and that many thoracic and pulmonary structures may be involved simultaneously. If the examiner is reasonably well convinced that in any one case he is confronted with an expression of pulmonary tuberculosis, it is desirable to move on to the evaluation of the location, extent and probable present status of the lesion. If, on the other hand, the evidence seems to point to some other type of disease, review and elaboration of the findings should be carried out to throw all possible light on its true character.

The reliable interpretation of fluoroscopic observations depends to a considerable extent on long practice and extensive clinical experience. In general, fluoroscopy is serviceable only in the detection of the character of movements. The substitution of fluoroscopy for radiographic methods is neither wise, safe nor even defensible, now that photofluorographic apparatus is available. Numerous modifications of the standard postero-anterior positioning of patients broaden the scope of chest roentgenography. These consist of projection in the direct lateral or the right and left anterior oblique positions, the use of the Potter-Bucky diaphragm (Chap. 2, pp. 36 ff.) to permit penetration of unusually dense parts, the insufflation of opaque fluids to outline the

course of the bronchi and many other technical procedures for particular circumstances. It is of utmost importance to master the fundamental steps in chest roentgenography before seeking to derive the diagnostic benefits afforded by the more highly specialized devices. The finest and most elaborate equipment obtainable, even though operated by the most adept technician, leaves a yawning gap between film evidence and its correct interpretation. This can be bridged with nothing short of sound medical knowledge intelligently applied. Every medical student and physician has within his grasp the ability to make telling use of his medical training in the interpretation of x-ray chest findings.

LESIONS OF NECK ORGANS, CHEST WALL AND MEDIASTINUM

At first consideration it might seem that of the many abnormalities related to the thorax, or in its immediate vicinity, those which involve structures other than the lungs and their coverings might properly be relegated to a position of minor importance. Actually, such abnormalities are sufficiently common and often of such great medical significance that one will do well to consider them carefully. So frequently do *lesions* of the chest wall and of the mediastinal structures simulate disease of the lungs that it is good practice to scrutinize these neighbors of the respiratory organs before proceeding further in the analysis of chest films.

SOFT TISSUES OF NECK. In any satisfactory x-ray projection of the chest it should be possible to identify the location and configuration of the trachea. Many times telltale deviation provides a lead to related abnormalities. Enlargement of the thyroid, aneurysms, intrathoracic tumors or fluid accumulations may press on the trachea, causing its displacement, while traction resulting from the contracture of scar tissue or the shrinkage of atelectatic lung may accomplish the same effect in the opposite direction. The larynx can be examined to good advantage in properly exposed films made in the lateral projection. In Plate 42, *A*, the epiglottis (*A*), the hyoid bone (*B*), the laryngeal ventricle (*C*), and the arytenoid cartilages (*D*) provide easily recognizable landmarks under normal conditions. Diseases

which affect the form and appearance of these landmarks produce fairly dependable roentgenologic signs. Laryngeal tuberculosis is commonly associated with edema and proliferative or destructive changes in the arytenoid cartilages. Laryngeal neoplasms often produce extensive distortion of the walls of the larynx, or they may be seen in part or in whole as shadows within the lumen, as in Plate 42, *B*.

THORACIC WALL. The detection of rib fractures by x-ray examination is not always as simple as one might expect, because the point of fracture may be hidden, at least in standard projections, by the shadows cast by mediastinal structures or by the great density of the liver shadow. When ribs are fractured along the midaxillary line, the defect may go unrecognized unless stereoscopic technic is used. Unless inspection of all parts of the chest is routine in the examination of chest films, traumatic lesions of the chest wall may escape notice. In Plate 42, *C*, the first three ribs on the right are fractured near their anterior ends, and some overlapping at the fracture site can be observed. In this patient's first x-ray examination after injury, the most prominent finding was subcutaneous emphysema and generalized haziness, the result of bleeding into the pleural space. These findings, which almost entirely obscured the underlying bony injury, disappeared in 10 days, and then the details of the bone defects could be seen much more clearly.

Sometimes lesions which at first inspection seem to be located in lung can be proved, on the basis of x-ray evidence, to involve the ribs and to be entirely outside of the parietal pleura. Associated abnormality of rib density—either decreased or increased calcium content may be observed—will indicate this, or immediately associated swelling or partial destruction of bone will be visible. In Plate 42, *D*, destructive changes in the second rib on the left are associated with a clearly demarcated soft tissue mass which, on surgical removal, was found to be an osteochondrosarcoma. Sometimes the introduction of air into the pleural space to produce partial collapse of the lung is necessary to identify the true nature of chest wall masses. Benign neurofibromas from intercostal nerve tissue arising along the posterior halves of ribs

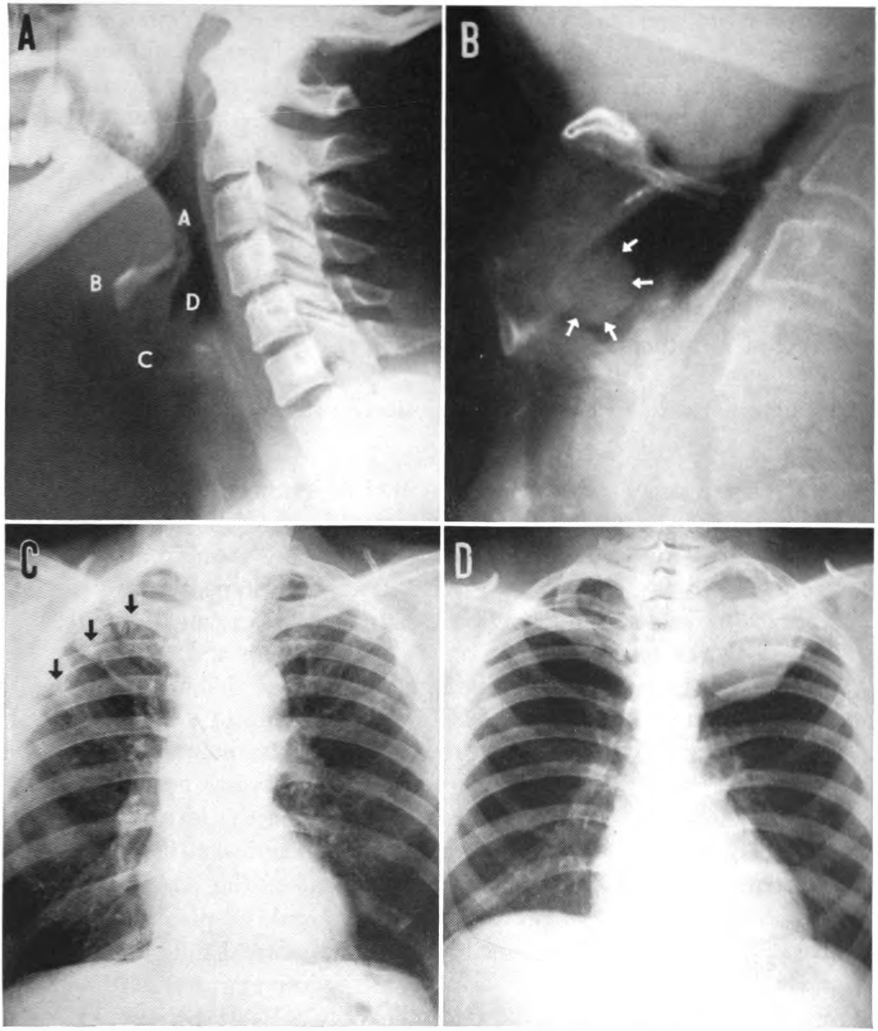


PLATE 42.—*A,* lateral view of larynx: *a,* epiglottis; *b,* hyoid bone; *c,* laryngeal ventricle; *d,* arytenoid cartilages. *B,* carcinoma of anterior laryngeal wall (arrows). *C,* fractures of ribs 1–3 (arrows). *D,* osteochondrosarcoma, rib 2, left.

are not uncommon. The smooth discreteness of their outlines, their tendency to develop as hemispherical masses flattened against the chest wall and their position, in lateral projection, relatively far posterior in the chest point to their true character.

Anomalies of development are quite common throughout the skeleton and the dorsal vertebrae and ribs are not excepted. Foreign bodies and soft tissue masses within the walls of the chest may at times be mistaken for intrathoracic lesions; stereoscopic examination is very helpful in their accurate recognition. Individual variations from the normal which x-ray methods can and do disclose are too numerous to mention. It should be sufficient to call attention to the necessity for careful inspection of chest wall structures as one of the first steps in the interpretation of chest films.

MEDIASTINUM. Among normal individuals a great deal of variability is to be expected in the shape of the composite shadow cast by the heart, the dorsal spine, the sternum and the aorta. After due allowances are made for body type, which profoundly affects the relative position of the heart, and for age, which works recognizable changes on the spine and the aorta, alterations in shape, configuration and size of the mediastinal shadow can be of considerable diagnostic value in determining the presence and even the nature of certain intrathoracic lesions.

In the upper mediastinum, above the transverse aorta, difficulties in diagnosis may be encountered when the identity of a rounded, dense mass must be determined. The lesion illustrated in Plate 43, *A*, may be considered typical of the condition it represents—substernal extension of the thyroid. Displacement of the trachea to the left indicates that the abnormal thyroid mass arises in the right lobe. Note that the shadow margins continue upward to merge with those of the cervical soft tissues. The shadow seems to ride upon the transverse aorta, which is typical. Observed fluoroscopically, the shadow should rise perceptibly and abruptly during deglutition. Intrathoracic extensions of the thyroid may be extensive and therefore deceptive. It is well to remember that, with rare exceptions, thyroid masses in the chest uniformly occupy a far anterior position. Aneurysms of the in-

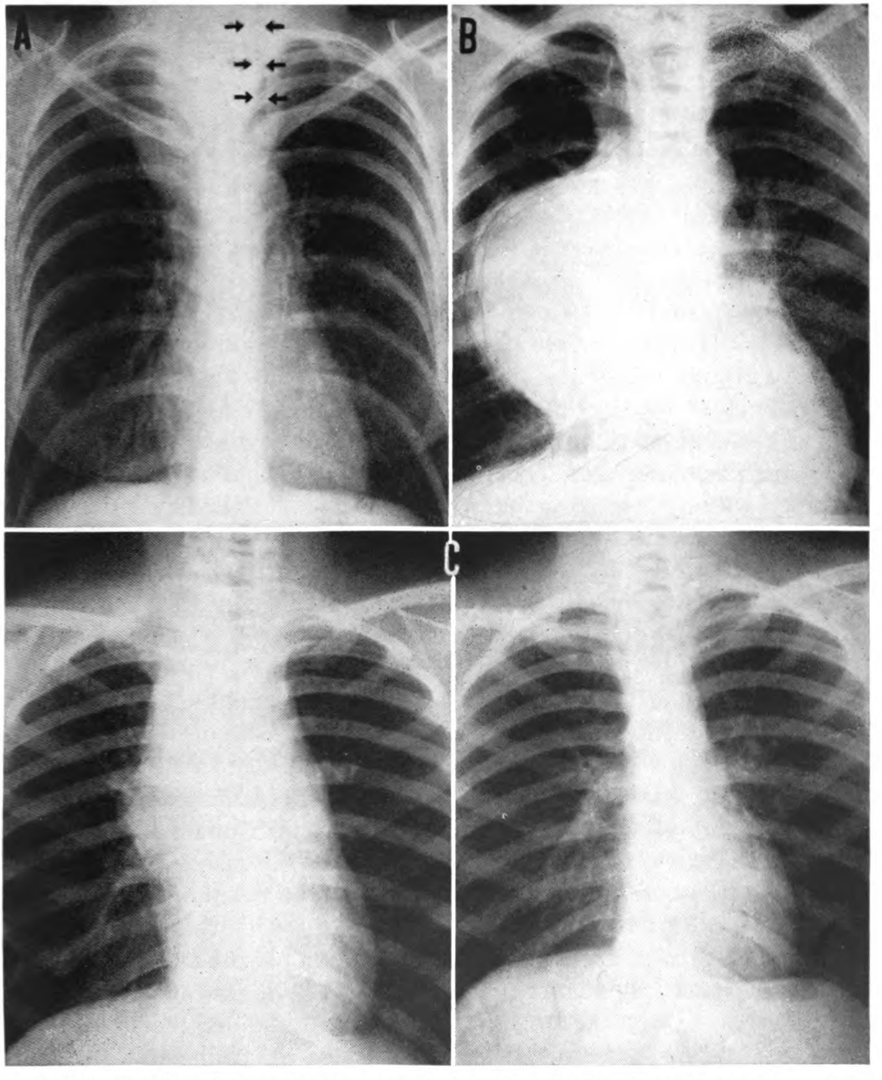


PLATE 43.—*A,* substernal extension of thyroid, with tracheal displacement (arrows). *B,* dermoid cyst of mediastinum. *C,* mediastinal Hodgkin's disease; disappearance one month after x-radiation.

nominate or carotid arteries, which are not uncommon, closely imitate in appearance the condition shown here. In general, such lesions do not produce tracheal deviation but show a decided tendency to extend toward the right. Other lesions found in this location which may be confused with substernal thyroid extension are far less common. Among them might be mentioned paratracheal cyst and superior mediastinal abscess.

Another intrathoracic lesion which characteristically occupies a far anterior position in lateral chest projection is teratoma of the mediastinum. Seen in frontal projection (Plate 43, *B*), the shadow it casts is almost perfectly round, lies in close contact with midline structures and is delineated by a sharp and almost continuous, dense white line which represents calcium salts deposited within its capsule. The characteristics exhibited by this particular example are constant. Usually teratomas are cystic and filled with a cholesterol emulsion. Sometimes hair and more solid, formed masses of epithelial elements are to be found. Although the cyst pushes its way toward the anterior mediastinal space as it increases in size, its point of attachment lies far posterior, and surgical approach for its removal is made from behind.

Mediastinal adenopathy, when it occurs in patients with lymphoblastoma, is capable of seriously deforming the contour of the shadow cast by mediastinal structures as a whole. No single roentgenologic characteristic will be found to hold for all cases. In general, however, such masses are most obvious at the level of the aortic arch, will project to both sides of the midline, will have slightly or more prominently lobulated margins and, in lateral projection, will be seen to extend into the anterior superior mediastinal space between the lung margins. The disappearance, or at least the profound shrinkage, of lymphoblastomatous masses when exposed to moderate doses of relatively high-voltage radiation may be spectacular and rapid. An example of mediastinal Hodgkin's disease which presents most of these diagnostic criteria, including virtual disappearance one month after radiation therapy, is seen in Plate 43, *C*.

In finding the most plausible explanations for related abnormalities that will be encountered in the examination of chest films, it is expected that the student will use his knowledge of

diseases which affect the mediastinal structures to amplify what has been presented here. Only when the status of the neck organs, the chest walls and the mediastinum has been determined to his satisfaction should the observer direct his attention to the lungs. To do otherwise is to court errors in evaluation of non-pulmonary abnormalities.

LESIONS OF THE LUNGS AND PLEURAE

Nontuberculous Pulmonary Lesions

Anomalies of the lungs do not constitute an important phase of chest diagnosis. Occasionally one will encounter profound faults of pulmonary development, and rarely a newborn infant will show the peculiar appearance produced by the migration of most of the abdominal viscera into the thorax owing to failure of the diaphragm to develop; but the commonest anomaly involving the lungs is the clinically unimportant subdivision of the right upper lobe by an anomalous branch of the azygos vein. On the film it appears as a threadlike line which begins at the extreme apex of the chest medial to the margin of the first rib and curves downward and medially to end in a "comma" mark close to the junction of clavicle and sternum.

Especially during childhood, though not entirely restricted to that period of life, foreign bodies of one sort or another may be aspirated into the air passages. If the foreign body happens to be made of metal or some other dense substance, its presence can be detected and its exact location determined accurately and readily by x-ray examination. An empty cartridge of small caliber lodged in the first portion of the right bronchus is shown in Plate 44, A. The shell is clearly identified in both views of the chest.

Many aspirated foreign bodies are not opaque to x-rays. Bits of food, nut meats and popcorn are frequent offenders in this group. Although they cannot be observed in their own right, the changes in pulmonary dynamics which their presence ordinarily provokes do give rise to characteristic and reliable diagnostic signs. In general, aspirated foreign bodies perform in one of two ways: they may block the ingress of air to lung beyond the point of lodgement, or they may stir up sufficient local edema of the

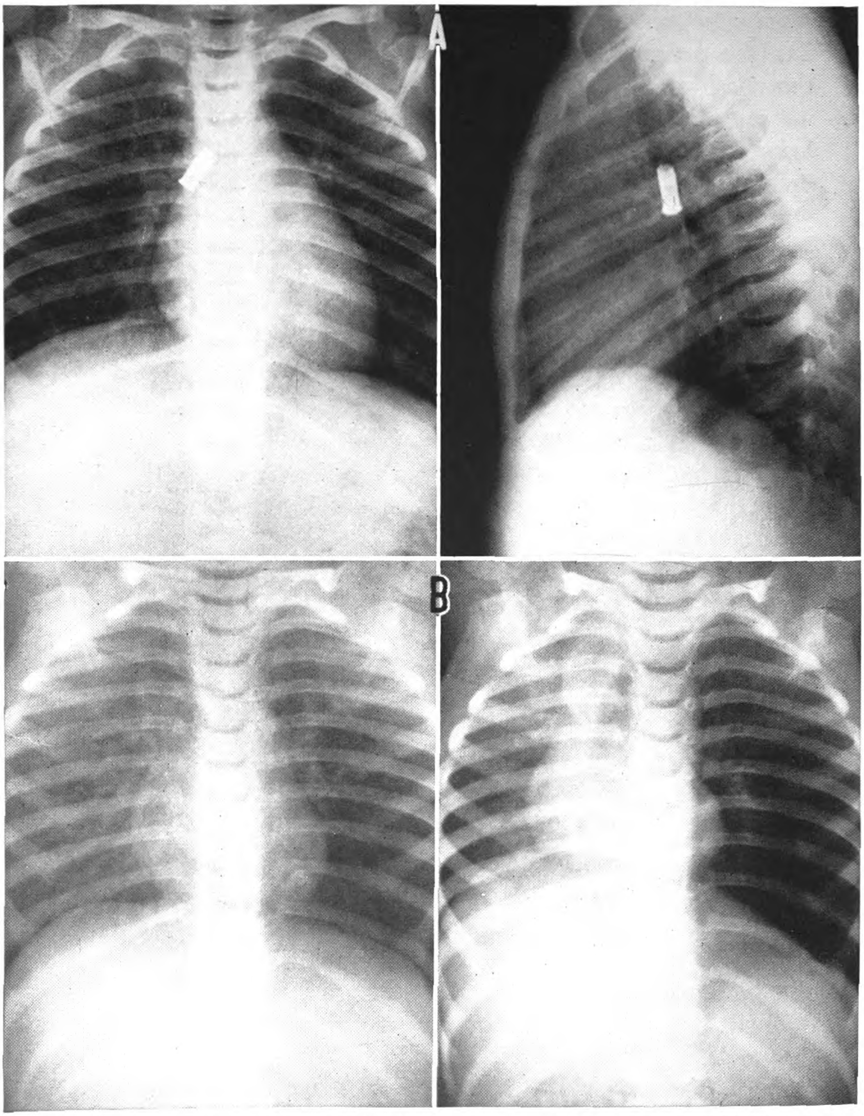


PLATE 44.—*A*, opaque foreign body (empty, small caliber cartridge) in right main stem bronchus, frontal and lateral projections. *B*, expiratory block, left main stem bronchus, from nonopaque foreign body; inspiration and expiration.

bronchus to form the seat of a valve which, in the manner of a ball-check valve, allows air to enter lung but by pressure against the edematous ring may prevent the escape of air during expiration when bronchial caliber is reduced. Whichever of the two phenomena occurs, the appearance of the chest at the fluoroscope, or by comparison of inspiration and expiration films, is spectacular and highly informative. To interpret the situation correctly it is necessary to identify the phase of respiration at the moment of exposure and to observe and think carefully and clearly. Accurate localization is, of course, of great advantage to the bronchoscopist who attempts to remove the foreign body; speedy diagnosis and prompt removal are desirable.

Normally both lungs inflate evenly with descent of the diaphragm during inspiration; deflation should be equal during expiration. No side-to-side movement or displacement of the heart should occur during the respiratory cycle. If a foreign body plugs a bronchus tightly enough to prevent the free ingress of air, trapped air in the lung beyond the point of bronchial obstruction will soon be absorbed. Since it cannot be replenished in the course of breathing, that portion of lung will rapidly become atelectatic. Depending on the volume of lung thus collapsed, the heart will be displaced, to a greater or less degree, *toward* the obstructed side during *inspiration* by full inflation of the normal lung and will return to normal position as the normal lung deflates during expiration. Relative opacity will be observed on the affected side during inspiration. In short, if the foreign body prevents the ingress of air, the distinctive x-ray signs will be apparent on the affected side during inspiration.

If, on the other hand, the foreign body is producing expiratory blockage of a bronchus, x-ray signs will be reversed and cardiac shift will be *away from* the affected side during *expiration*, while at the same time the normal lung, normally deflated, will appear denser than the obstructed lung (Plate 45, *right*). Expiratory block of the left main bronchus is beautifully illustrated (Plate 44, *B*) by inspiration and expiration films. Note that the right half of the diaphragm has moved upward a full interspace during expiration, with no corresponding movement on the left. In this instance the offending peanut was promptly re-

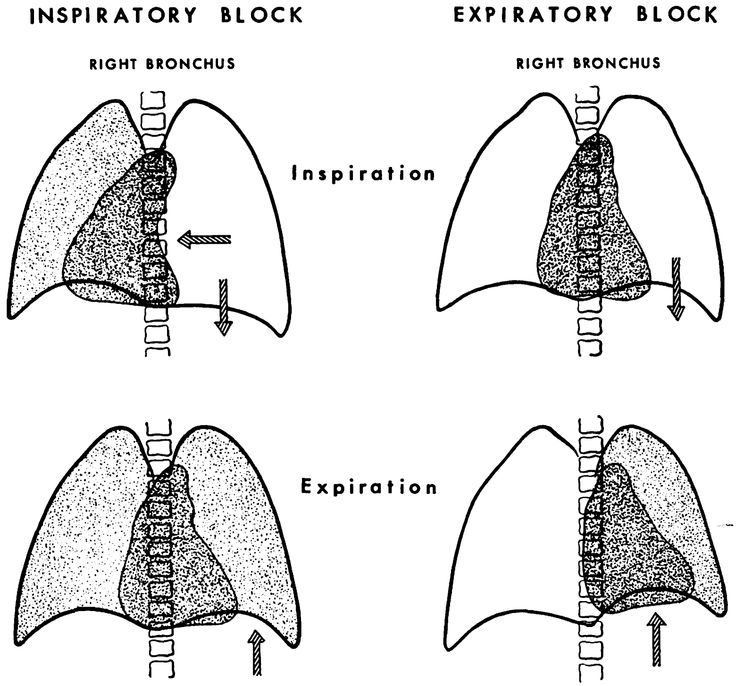


PLATE 45.—Abnormal pulmonary volume changes associated with bronchial obstruction. If little or no air can enter the lung, no expansion will occur on the affected side during inspiration and the expanded normal lung will displace mediastinal structures *toward* the side of obstruction. Both lungs will appear deflated (i.e., less translucent) during expiration and the mediastinal displacement will no longer exist.

If air can enter the lung but is prevented from leaving during expiration, both lungs will be inflated on inspiration; but when the normal lung deflates, the lung in which the bronchus is obstructed will remain air filled and will displace the mediastinum *away* from the side of obstruction.

moved by the bronchoscopist and the patient recovered rapidly and completely. It is not necessary to be able to see the shadow of the foreign body to detect its presence.

Initial fluoroscopic examination followed by filming is the standard procedure in cases of suspected bronchial obstruction. It should be remembered that it is not impossible for foreign bodies to change position within the bronchial tree; consequently, the patient should be examined shortly before removal is attempted.

Bronchial obstruction can be produced by situations other than foreign-body aspiration. For example, tumors arising within the bronchus or in closely adjacent lung can cause partial or complete obstruction of the lumen and give rise to atelectasis of lung peripheral to the obstruction. Inflammatory bronchostenosis sometimes occurs, particularly in advanced pulmonary tuberculosis.

Before the importance of stimulating the resumption of normally deep breathing and coughing after periods of anesthesia was recognized, deaths from postoperative pneumonia were encountered with distressing frequency. Massive postoperative collapse, if promptly recognized, can be relieved by bronchoscopic aspiration of the offending plug of secretions. The condition can be prevented by postanesthesia precautions now routinely employed. The profound degree of collapse which can be produced by bronchial plugging with sputum and followed by rapid reexpansion after aspiration is well illustrated in Plate 46, *A*. Lobar pneumonia, like complete bronchial obstruction with atelectasis, renders lung largely non-air-containing and therefore relatively opaque to x-rays. In pneumonia, however, shrinkage of lung volume is almost negligible; whereas atelectasis is associated with striking reduction in volume. Compare the appearance of right upper lobe pneumonia shown in Plate 46, *B*, with the example of massive collapse. Note that there has been no shift of the trachea and heart because lung volume has not been significantly decreased. Since the introduction and wide use of antibiotics, full-blown lobar pneumonia in the stages of red and gray hepatization is seldom encountered. Effective treatment during the early stages of the disease aborts the process before x-ray signs, which are dependent on the widespread replacement of alveolar air by

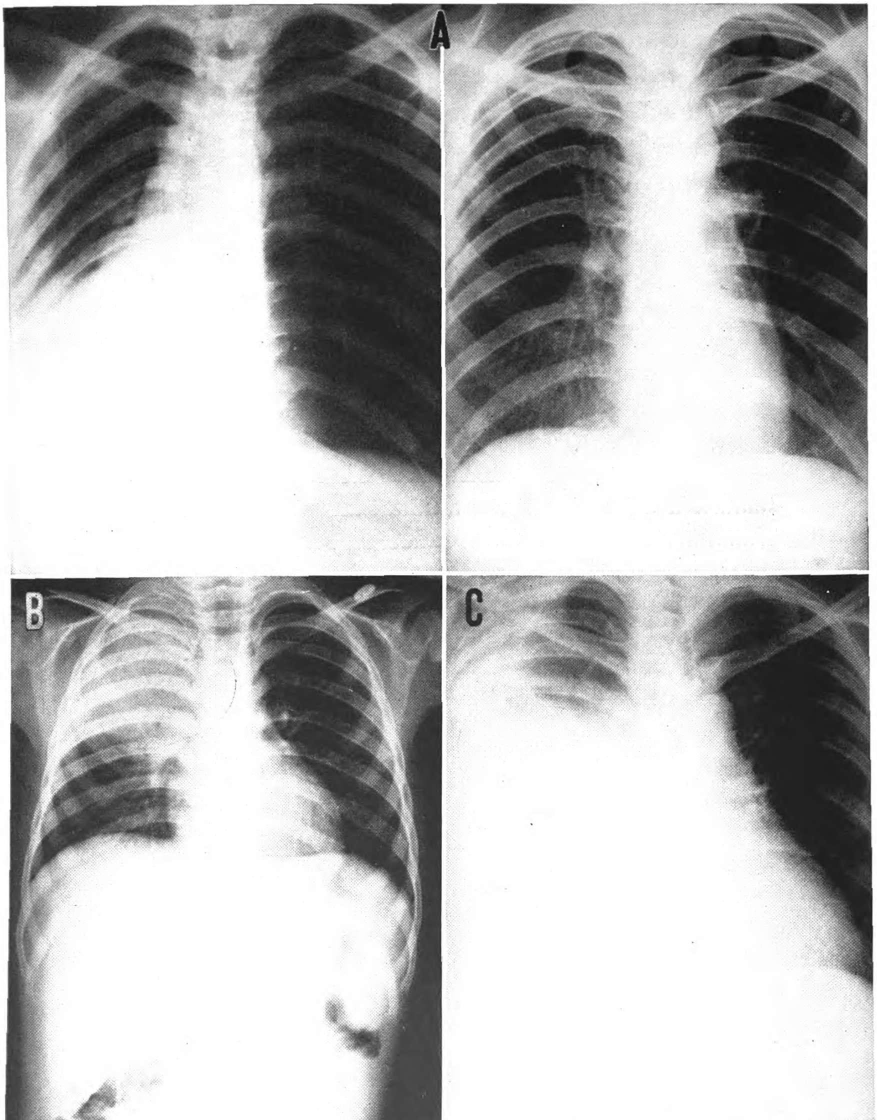


PLATE 46.—*A*, massive postoperative collapse of middle and lower lobes, right lung; complete re-expansion one week later. *B*, lobar pneumonia, right upper lobe. *C*, massive pleural effusion, right.

fluid exudate, have had time to develop. In present-day practice it is necessary to diagnose lobar pneumonia roentgenologically on the basis of poorly defined evidences of diminished, rather than almost totally absent, air content. Bronchopneumonia, especially in children, often produces overinflation of both lungs, owing to the check-valve effect of edematous bronchi or multiple mucus plugs.

Sometimes the lung may be compressed from without. This occurs, for example, when the potential space between the parietal and visceral layers of the pleura contains considerable quantities of fluid, organized exudate, blood or air. In these circumstances mediastinal structures are displaced away from the affected side, and, except in the case of pneumothorax, the normal transparency of the chest is replaced by great density. The extent of the abnormal density and the location and shape of the shadow are related to the amount and location of the material which occupies the pleural space. In Plate 46, *C*, the shadow of opaque fluid extends from the base of the chest to the extreme apex, pushing the partially collapsed right lung upward and medially and displacing the mediastinum to the left. Note the obvious displacement of the trachea, and observe that the lower and middle lobes of the right lung are more sharply collapsed and almost totally concealed by the large pleural effusion.

As an insidious sequel to incompletely resolved pneumonia, or perhaps to primary inflammatory disease of the bronchi themselves, partial obstructions to the smaller airways may develop and lead to irregular enlargement or actual sacculation of the lesser bronchial divisions within one or more lobules or lobes of lung. This complication, bronchiectasis, cannot be recognized with certainty without recourse to bronchography. It is not difficult to introduce into the bronchi bland oily or water-soluble halogenated compounds in sufficient quantity to coat the bronchial mucosa and thereby render the larger and smaller airways visible to x-ray. After preparatory local anesthesia to depress the cough reflex, the opaque material can be introduced into either or both main bronchi by tracheal catheter, by subglottic injection with an appropriate syringe or even by passive aspira-

tion. In young children it may be necessary to resort to general anesthesia to obtain satisfactory bronchograms.

When administration of opaque material is conducted under fluoroscopic control, it is possible, by purposeful positioning, to cause filling in the particular parts of the bronchial tree one wishes to examine. Since much of the bronchial tree is normally hidden by the mediastinal shadow in frontal projection, oblique and lateral views are desirable if all branches are to be seen. With stereoscopic technic the ramifications of both bronchi can be observed simultaneously, but separate examinations of the right and left sides yield results of greater nicety. *Left* anterior oblique projection (the patient facing the film at an angle of 45 degrees with the left shoulder in contact with the cassette holder) produces the best results when the *right* bronchus is to be studied. Plate 47, *A*, shows a normal right bronchogram in which the left anterior oblique position has displaced the shadow of the spine toward the left without allowing the cardiac shadow to obscure the bronchus too seriously. At the right the same chest at the same sitting is shown in direct right lateral projection. Taken together, these two films provide an excellent opportunity for the observer to inspect the right bronchus in all its ramifications. Note the delicacy of the finer bronchi as shown in these illustrations.

By way of contrast, observe the obvious distortion of small bronchial branches in the upper and middle lobes of the right lung and in the apical portion of the lower lobe in Plate 47, *B*. The technic of bronchoscopy is useful in a variety of situations—in fact, whenever it is desirable to determine the relationship of the bronchi to any lesion. In bronchiectasis, bronchography is an essential preliminary step if surgical removal of affected lobes or parts of lobes is contemplated. In this case the mapping of *all* bronchi should be carried out because, although this disease is most commonly found in the posterior portions of the lower lobes, the middle lobe on the right and the corresponding lingular portion of the left upper lobe may also be involved.

Although the nontuberculous lesions of lung and pleura which can be investigated to advantage by roentgenologic means are far too numerous and too varied to illustrate or even to enu-

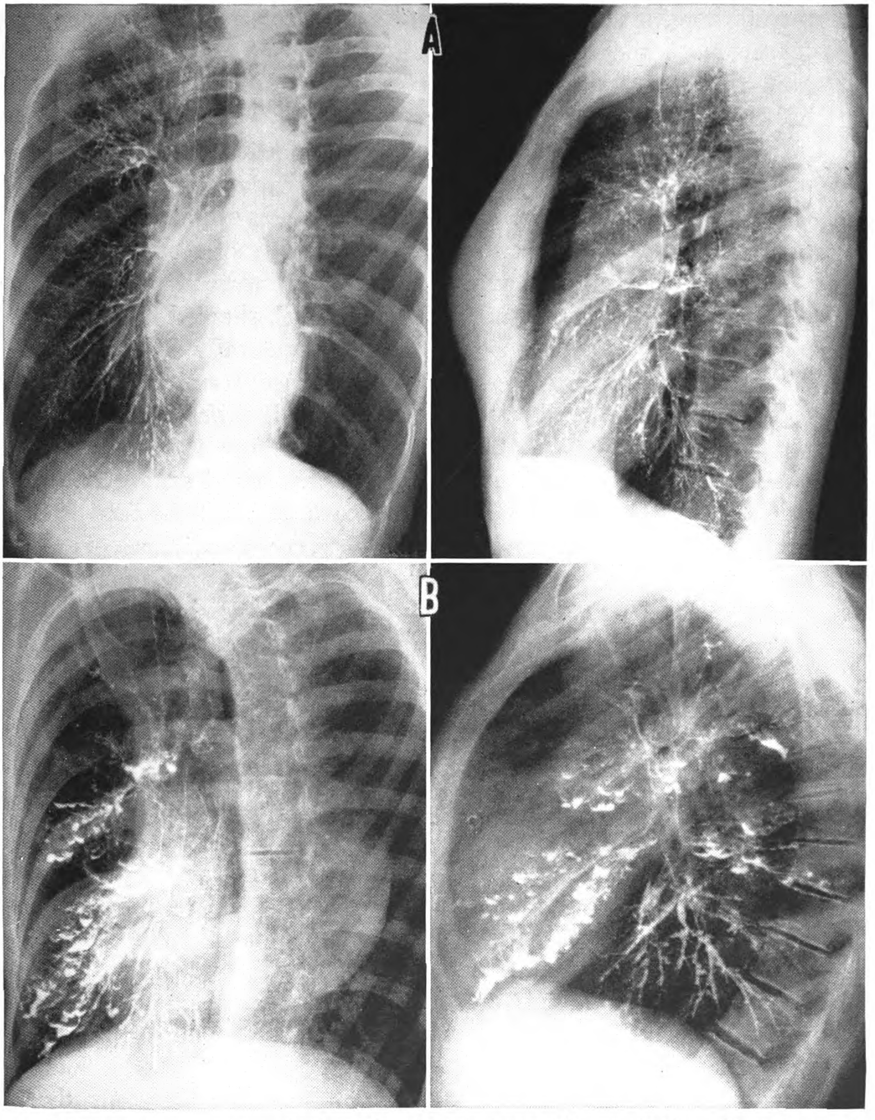
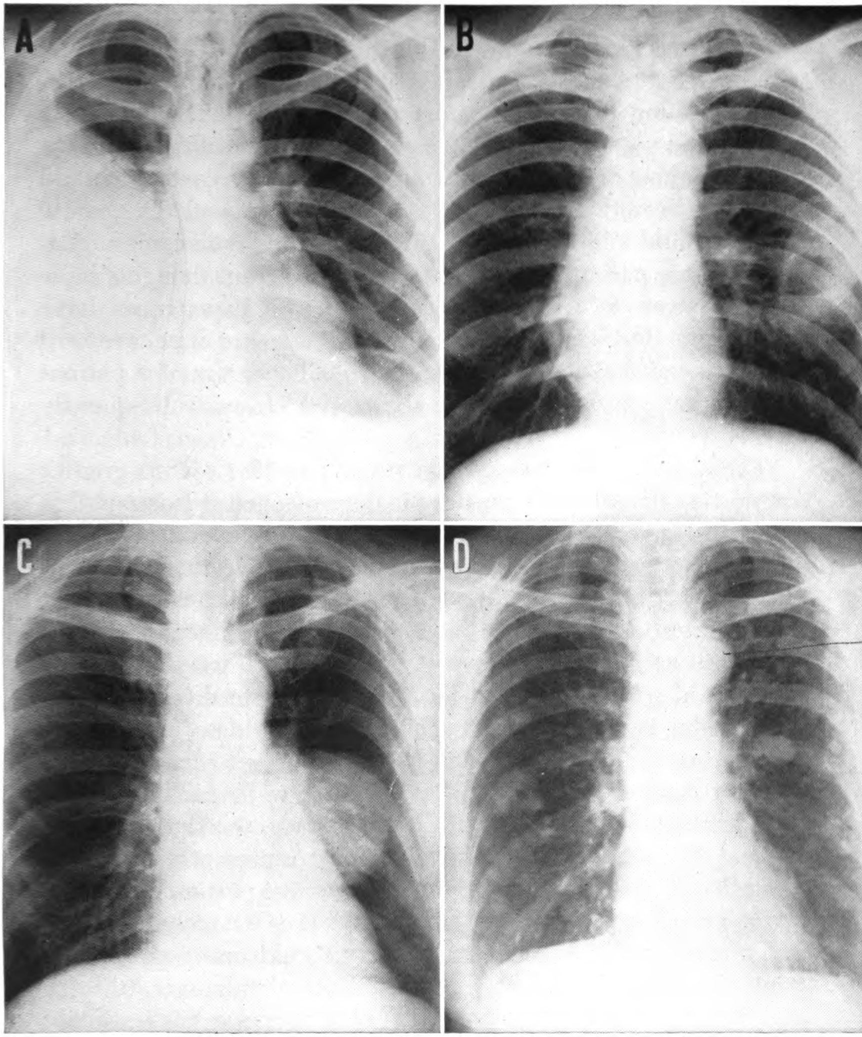


PLATE 47.—*A,* normal right bronchogram: anterior oblique *(left)* and lateral *(right)* views. *B,* same projections, saccular bronchiectasis *(right).*

merate here, a few more examples should serve to illustrate the relatively simple reasoning which often is effective in linking abnormal roentgenologic appearances to diseases with which one has made previous acquaintance. It is true that initial frontal projection films often do not provide the particular bit of information on which a reasonably accurate anatomic diagnosis can be based. One should be well satisfied if such examination does no more than convince one of the advisability of searching further and of using other available x-ray procedures.

Even without the lateral projection which showed the abnormal shadow to lie posteriorly as well as laterally in the right chest, Plate 48, *A*, suggests that the dense opacity, with its clearly defined curved medial border, in all probability represents an accumulation of pleural fluid because it follows the chest wall and displaces lung. One might think of some type of primary neoplasm arising in pleura or rib, and yet the fact that the shadow tapers off to a thin line near the apex is scarcely in keeping. If this is fluid, why does it not spread throughout the entire pleural space? The sharply convex medial contour of the shadow suggests that this particular accumulation of pleural fluid is encapsulated and therefore cannot spread freely. Can one take the next inviting step and postulate that encapsulation bespeaks purulence of the fluid? That supposition was made in this instance; the most advantageous point for puncture was recommended; pus was aspirated for culture—all on the basis of roentgenologic evidence.

What of the startling lesion at the level of the third interspace anteriorly which is depicted in Plate 48, *B*? Without clinical information of any sort it is certain that this individual harbors a significant abnormality. A lateral film will show it to be situated in the lung, well separated from the chest wall at all points; it will tell us, moreover, that the abnormality is, as we might have expected, a hole in the lung partially filled with fluid which has sought its level along the bottom. The halo of slightly increased density which closely surrounds the hole must be lung which for some reason has lost its normal capacity to inflate with air. Considering rapidly the possibility that this may represent a tuberculous cavity or an emphysematous bleb, one may



Aortic notch,

PLATE 48.—*A*, encapsulated fluid on the right; aspiration yielded pus. *B*, postpneumonic pulmonary abscess, left lower lobe. *C*, primary bronchial carcinoma, left lower lobe. *D*, multiple pulmonary metastases from carcinoma of uterus.

discard such notions by pointing out that solitary tuberculous cavities are seldom encountered in this locality and almost never without more extensive and less well-defined surrounding disease; that lung blebs are characteristically situated immediately beneath the pleura; and that, since they are in reality highly expanded pulmonary alveoli and atria, the cavity contour should show as a very thin line rather than as a thick band. The cavity contents—fluid and air—prove that the opening is in communication with air passages. Long before these vagrant thoughts have been followed to their conclusion, our past experiences have whispered: "Pulmonary abscess"; and if we are wise, we will heed that voice. This is, in fact, the roentgenogram of a patient who did have a postpneumonic abscess which was subsequently drained surgically.

The obvious abnormality shown in Plate 48, *C*, offers greater diagnostic difficulties. From this single projection it is impossible for us to locate the lesion with respect to the anterior and posterior chest walls. Stereoscopic films would give the answer to this without equivocation, and it is for such reasons that chest films are routinely prepared "in stereo." A single lateral exposure would tell as much, of course. As a matter of fact, this sharply demarcated spheroidal mass, located posterior to the heart, does not pulsate, is not closely associated with the descending aorta and is surrounded by air-filled lung except where it seems to come in contact with the posterior chest wall. All these facts were learned by the use of additional x-ray procedures. One is inclined to conclude that this lesion must represent a neoplasm which has had its point of origin in the apical portion of the left lower lobe. Why a primary neoplasm? It is scarcely probable that metastasis from a distant primary would occur at a single point along the course of the pulmonary circulation, although occasionally this does happen. Can one hazard a guess, a considered opinion, as to the nature of the neoplasm if, in fact, this is a neoplasm? The most commonly encountered primary neoplasms arising in lung are malignant. Although this lesion somewhat resembles the frontal projection of a mediastinal dermoid cyst, its posterior location deep in lung is incompatible with that diagnosis. This particular lesion was found to be a

primary bronchogenic carcinoma which had grown to considerable size without producing sizable bronchial obstruction. Bronchial carcinomas are often recognized by the obstructive atelectasis which they have produced rather than by the actual shadows of the tumors themselves. Pulmonary abscesses similar to the abscess shown in Plate 48, *B*, may represent central liquefaction necrosis in primary malignant tumors, and this explanation should always be considered.

The discovery of solitary, discrete, circular shadows in the chest surrounded by aerated lung has come to be considered very ominous because a great many patients with such findings in the absence of pulmonary or systemic symptoms of any sort have been observed to go on to death from malignant primary bronchial neoplasm. The absence of worrisome symptoms is no valid basis for complacency. Positive preoperative differentiation of ominous primary malignancy, smoldering or fully arrested pulmonary tuberculosis or other granulomatous disease and uncommon examples of benign pulmonary tumor cannot be made on the basis of roentgen examination alone. On the other hand, radiologists can, once they are alerted to the possible implications of such findings, be of enormous service in calling attention to the existence of such shadows even when they are very small. The lesson to be learned is that no such isolated shadow, often referred to by the somewhat misleading term "coin shadow," can safely be disregarded or lightly ignored. The rule of thumb which says that most such lesions, if they can be proved to lie close to a pleural surface, will prove to be tuberculous in nature, particularly if central calcium deposits can be demonstrated, is no more than a rule of thumb. The only safe course to pursue is surgical exposure and excision.

The appearance of sharply outlined, soft tissue masses of spherical shape—whether few or many, large, small or of various sizes—must always lead one to suspect pulmonary metastases from some primary malignant tumor (Plate 48, *D*). Experience teaches that it is altogether futile to guess what manner of tumor, carcinoma or sarcoma, or what parent organ or tissue has produced the ball-like masses which invade lung. In this instance the visible shadows of breasts might lead one to rely on the top-

heavy incidence figures in women of mammary carcinoma or of carcinoma of the uterine cervix to transform an outright guess into something which might pass for diagnostic acumen. Either diagnosis would be in error, for, following autopsy, the histologic pattern of a representative pulmonary mass was found to match that of the primary papilliferous cystadenoma which had extensively involved the corpus of the uterus.

Pulmonary Tuberculosis

Mass radiography of the chest has come to be widely used in tuberculosis case-finding. However accomplished, whether by means of 14×17 in. transparent film, full-sized paper negatives or the photofluorographic method with the use of miniature film, mass surveys of various population groups are accepted as a highly utilitarian means of determining which individuals within such groups have pulmonary tuberculosis. It is doubtful whether any diagnostic procedure employed in the practice of medicine has ever achieved the distinction of producing uniformly exact and unequivocal evidence under all conditions. Certainly, all modifications of the x-ray surveying of chests are open to the criticism that, on occasion, certain instances of extremely early tuberculous disease will be overlooked, and thus both patient and examiner will have a fallacious sense of security. It may be argued with equal force and justice that on other occasions abnormal pulmonary shadows representing conditions entirely innocent of clinical significance will be erroneously interpreted as evidence of pulmonary tuberculosis, with resultant unnecessary anxiety for the individual. The fact remains that by no other single device now available can the incidence of this important and widespread disease be determined with equal accuracy, speed and facility. One should not overlook the fact that it is possible, by annual repetition of such surveys, to rectify many errors of omission in the case of very early lesions or the fact that many an example of well-advanced pulmonary tuberculosis has gone unrecognized until discovered by mass survey methods. Discoveries of advanced cases are of far greater significance from the public health standpoint, and in this category errors of omission do not occur.

Whereas the roentgenologic signs produced by pulmonary tuberculosis at various stages and in its many manifestations differ so widely that any attempt to define their characteristics would be futile, some of the more outstanding and commonly encountered findings can be presented in the form of illustrations. This field of diagnosis is not without its pitfalls. Many diseases which affect the respiratory organs produce x-ray signs entirely indistinguishable from those found in tuberculosis. Not infrequently the roentgenologist must content himself with the determining of the presence, size, location and configuration of a pulmonary lesion without being able, in all honesty, to postulate tuberculous etiology in differentiation from brucellosis, sarcoidosis, nonspecific bronchopneumonia or interstitial fibroid pneumonia or any of a considerable variety of underlying pathologic processes. Here he must welcome diagnostic assistance from sources other than the use of x-rays.

TUBERCULOUS PULMONARY AND PLEURAL SCARS. With great frequency, initial or primary tuberculous infection is followed by spontaneous and more or less complete healing. Often the entire episode occurs without the person's knowledge and without the benefit of medical assistance. This person is most fortunate because he has been spared not only great loss of time and mental anguish but also the consequences of propressive involvement and destruction of lung and other organs which would have followed infection if his natural defenses had been less efficient. It is certain that spontaneous healing of primary lesions often occurs, because telltale calcium-containing scars (associated with positive tuberculin skin reaction) are commonly found in the x-ray examination of patients' chests when no articulate medical history of tuberculosis is obtainable. Dense deposits of lime salt in pulmonary tissues constitute strong presumptive evidence of tuberculosis which, becoming quiescent, has followed well-recognized steps in the pathology of the disease to the point of complete healing. Such evidence is presumptive rather than conclusive, because similar scars can develop in the healing of lesions other than those of tuberculosis. Histoplasmosis and coccidioidomycosis, for example—much more

common and more widely distributed diseases than we were once led to believe—can, and commonly do, heal by calcification.

The usual point of primary tuberculous infection is in the alveolar portion of lung and, apparently by preference, in the upper lobes. Neighboring pleura and lymph nodes near the hilum toward which lymph from the site of the lesion is collected are often invaded by organisms carried along in the lymph flow. Initial infiltration and multiple tubercle formation followed by caseation, fibrosis and calcification are the pathologic processes which occur in sequence to produce the scars associated with completely healed primary tuberculous lesions. Zones of caseation, seen microscopically, represent single or conglomerate tubercles which have become necrotic, and this accounts for the globular shape of the masses of lime salt which are subsequently deposited and which one sees when such lesions are viewed stereoscopically in roentgenograms. Plate 49, *A*, shows the stark remnants of a once active primary tuberculous lesion which "burned" itself out and healed by calcification after involving the regional lymph nodes at the hilum. This is a Ghon complex.

Many such lesions, which were in an active state simultaneously (*B*), probably represent histoplasmosis.

Plate 49, *C*, shows multiple bilateral primary complexes confined to the apical portions of the upper lobes and no visible calcium deposits in the hilum lymph nodes. A purely incidental finding is seen in the fifth rib on the left, which is fork-shaped at its anterior extremity, a common anomaly of development.

The patient whose chest findings are illustrated in Plate 49, *D*, fared less well in fighting off tuberculosis following primary infection. In his case the battle between the tubercle bacillus and the defense forces was more evenly matched; he needed the assistance of medical treatment, which was neither sought nor provided. There are many x-ray signs of partial healing to the point of fibrous tissue proliferation with subsequent and progressive contracture of the scar tissue. Suspicious signs of excavation within the dense masses throughout both upper lobes point ominously to the probability that the disease has never been fully defeated. Attention is called to the tortuosity of the trachea,

Ghons complex

Lesion

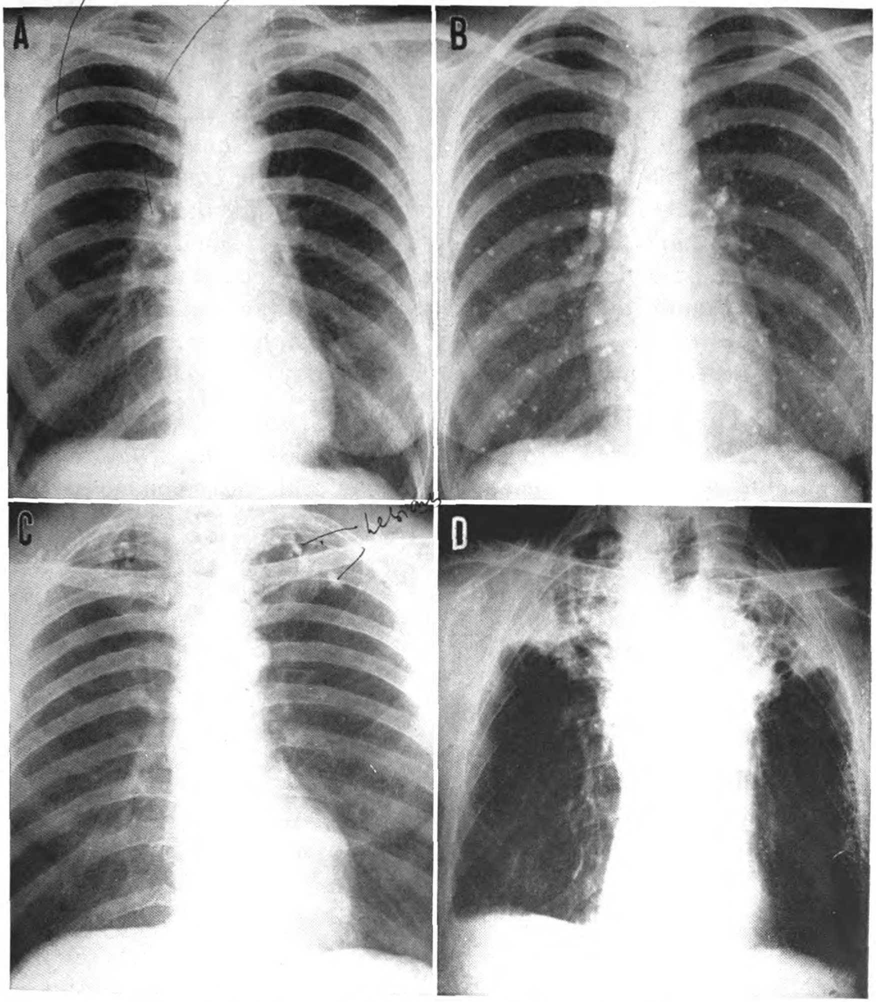


PLATE 49.—*A*, calcified lesions of tuberculosis, right upper lobe parenchyma and right hilum (Ghon complex). *B*, multiple calcified lesions, both lungs and many lymph nodes; probably healed histoplasmosis. *C*, multiple bilateral apical Ghon complexes. *D*, extensive bilateral upper lobe tuberculosis of long standing.

the result of marked contracture of the heavily scarred upper lobes. The pulmonary blood vessels which ordinarily spread out radially from the hila seem to follow an almost vertical course, because the pulmonary hila, together with the major bronchi and the great vessels which enter and leave the lung, have been forcibly displaced upward, again by scar-tissue contracture.

These few illustrations provide much food for thought in the consideration of the processes by which active tuberculous lesions approach or achieve healing. In the same low-power field, microscopic examination will show many stages of the pathologic processes typical of active chronic pulmonary tuberculosis. One must expect some reflection of this in x-rays of similar lesions.

EXTENT OF ACTIVE LESIONS. Throughout the United States, standardized terms have been developed and are widely used to describe the extent and character of the active pulmonary lesions of tuberculosis. The disease is considered to be of *minimal extent* if the volume of lung involved does not exceed the amount of pulmonary tissue outlined by the curve of the second rib. A lesion is classified as minimal regardless of its location if this crudely defined volume is not exceeded and if no sign of excavation can be discovered. It is most difficult to reproduce such lesions on paper during their active stages, not because of their small size but because they are relatively poorly defined until their shadows become dense as a result of the scarring process. In Plate 50, *A*, an attempt has been made to demonstrate a recently developed minimal lesion in the right upper lobe in the first intercostal space anteriorly. Although this small zone of impaired pulmonary transparency is by no means obvious, either in the original film or as here reproduced, it is entirely possible under good working conditions to recognize significant signs of minimal tuberculosis which are even smaller and less clearly defined. The observer much search intently for the slightest indication of impaired pulmonary transparency if truly early signs of pulmonary tuberculosis are to be detected with regularity.

Pulmonary tuberculosis has become *moderately advanced* if excavation measuring less than 4 cm. in diameter is apparent. With or without cavity, when lesions involve more volume than

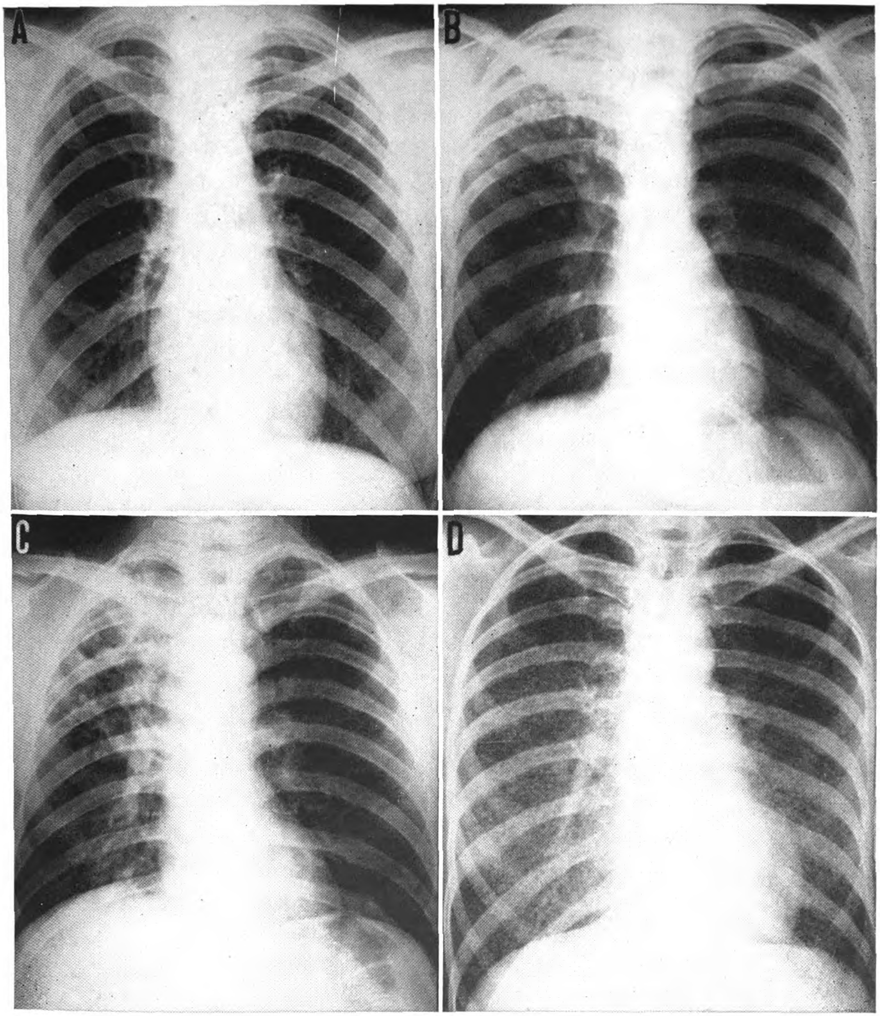


PLATE 50.—*A*, minimal tuberculous lesion, first interspace, right, anterior. *B*, moderately advanced tuberculous lesion, right upper lobe. *C*, far-advanced tuberculous lesion, right upper lobe. *D*, finely granular bilateral lesions, miliary tuberculosis.

the arbitrary minimal limit, the disease is moderately advanced, provided it is confined to a single lobe. Cavities are measured from 14 × 17 in. films. If more than one cavity is present, the sum of their diameters must not exceed 4 cm. The fluffy opacities throughout the right upper lobe shown in Plate 50, *B*, represent moderately advanced tuberculosis.

Again by definition, when tuberculosis involves more than one lobe or exhibits signs of excavation more extensive than the limits set for moderately advanced lesions, the disease is said to be *far advanced*. It is a matter of experience that, within limits, these arbitrarily fixed expressions of extent also indicate the degree of difficulty to be expected in effecting cure of the disease.

Plate 50, *C*, illustrates an example of pulmonary tuberculosis which fully qualifies as a far-advanced lesion. Note the sizable cavity just below the right clavicle. Note also patches of diminished transparency well below the limits of the upper lobe and fainter lesions at the apex and in midlung on the left.

Often enough to keep roentgenologists on the alert when reading chest films, patients are encountered whose films show finely disseminated granular shadows scattered throughout both lungs. *One* of the diseases which can produce this appearance is *miliary tuberculosis* (*D*). Unfortunately, there is no x-ray feature by means of which miliary tuberculosis can be differentiated with certainty from Boeck's sarcoid, miliary metastases from a malignant tumor, coccidioidomycosis, pneumoconiosis or any one of 100 or more diseases similarly expressed. It *is* possible to recognize the presence of widespread granular lesions even when they are much smaller and far less distinct than those shown here. When such lesions represent tuberculosis, the disease has gained a tremendously strong foothold, and (unless recently developed therapeutic agents such as streptomycin prove effective) at this stage the outcome is almost uniformly fatal.

RADIOGRAPHY DURING TREATMENT. Over and above tuberculosis case-finding and the evaluation of lesions once discovered, the planning and controlling of medical and surgical treatment of pulmonary tuberculosis largely depend on roentgenologic procedures. The illustrations in Plate 51 have

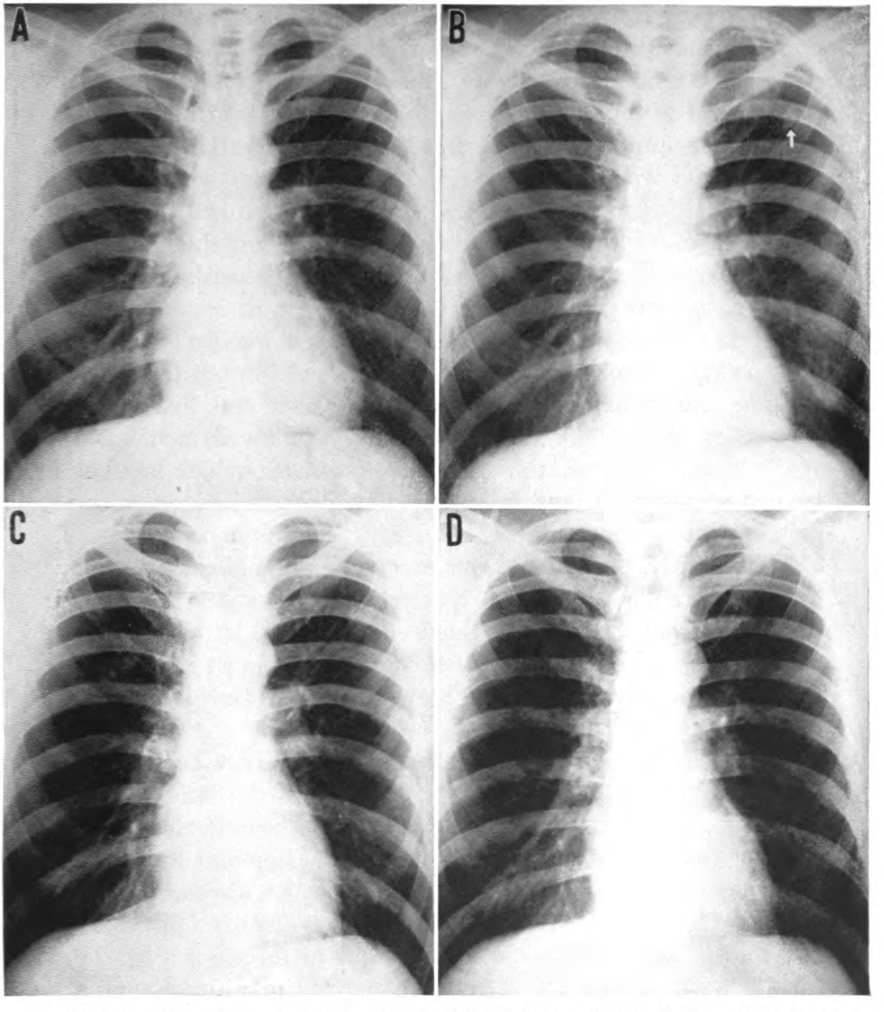


PLATE 51.—*A*, normal. *B*, minimal tuberculous lesion (arrow) three months later. *C*, fading of initial lesion; new region of involvement in opposite lung at level of second interspace. *D*, complete return to normal 2½ years later.

been selected from the considerable file of roentgenograms prepared during the treatment of a single patient. The great value of periodic x-ray examination of the chest is shown in this series, for the life history of the tuberculous process can be followed from its beginning. On Sept. 27, 1940, no suggestion of pulmonary disease was apparent (*A*). Some time between then and Jan. 3, 1941, a small but highly significant lesion had developed at the level of the first anterior interspace on the left (*B*). Tubercle bacilli were recovered from stomach washings.

Two months later, under strict bed-rest management, the lesion on the left was seen to have faded remarkedly (*C*), but a new point of involvement was seen in the vicinity of the second anterior interspace on the right. Two years and five months later (*D*) the patient, having faithfully followed medical advice, showed no detectable trace of the disease, which had been treated so promptly and so simply. The process had never been permitted to progress to the stage of caseation or cavitation. Detected early, the lesion never exceeded minimal extent. Today the same result could be expected with a greatly shortened period of invalidism through the use of highly effective antituberculous chemical agents. "Early treatment" is almost synonymous with "effective treatment." From every point of view it is profitable to bear this in mind.

A much more advanced case of pulmonary tuberculosis is shown in Plate 52, *A*. The bilateral nature of the lesions in this case complicated the matter of treatment. Bed rest alone failed to bring about complete resolution. Artificial pneumothorax was instituted on the right four months after the disease was discovered (*B*). Note that the more extensively involved upper lobe has shrunk more than the other portions of the right lung. This phenomenon, known as "selective collapse," may represent partial bronchostenosis or the contracture of pulmonary scar tissue.

When the patient had adjusted himself to the diminished vital capacity of unilateral pneumothorax, the same procedure was started on the opposite side (*C*). Note the pleural adhesions which partially suspend the shrunken lungs. Fortunately, these have stretched gradually, permitting a sufficient degree of collapse to hasten healing. A roentgenogram made a little more

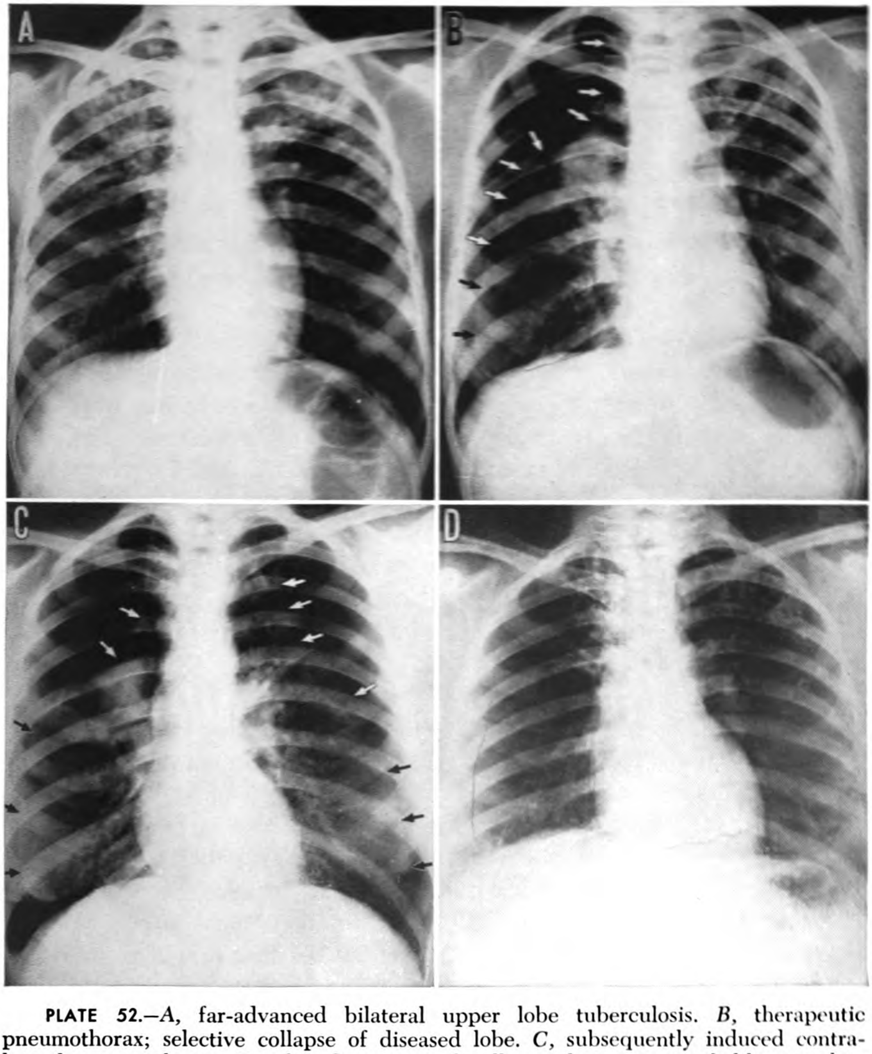


PLATE 52.—*A*, far-advanced bilateral upper lobe tuberculosis. *B*, therapeutic pneumothorax; selective collapse of diseased lobe. *C*, subsequently induced contralateral pneumothorax. *D*, after five years of collapse therapy; remarkably complete healing.

than five years later (*D*) indicated that calcified scars were all that remained to bear witness to the fact that this patient once harbored far-advanced bilateral tuberculous disease.

Therapeutic pneumothorax, once a powerful tool in the treatment of pulmonary tuberculosis, is now seldom employed, again because chemotherapy has become so very effective. The same can be said for therapeutic pneumoperitoneum, which consists of periodic introduction of air into the peritoneal cavity to displace the diaphragm upward and which was thought by many to be more satisfactory than pneumothorax.

In multiple stage thoracoplasty, one of the more heroic measures used to combat unusually far-advanced or stubborn disease processes, frequent x-ray examination is particularly important. Like most of the overt methods used in the treatment of refractory lesions, thoracoplasty aims to collapse diseased portions of lung to encourage natural reparative processes. The extent of collapse produced and maintained is of vital interest. Plate 53, *A*, shows the state of affairs which prompted the use of thoracoplasty in one instance. The right hemithorax is reduced in volume, resulting in the decided shift of the trachea and other mediastinal structures toward that side. The lung is contracted and the pleural space is largely filled with fluid. The right half of the diaphragm cannot be identified, but in all probability it has been elevated, again in response to profound contracture of the right lung. It is virtually certain that stenosis of bronchi is in part, at least, responsible for the partial collapse of lung.

The partial obliteration of the right half of the thoracic cavity (Plate 53, *B*) is the result of the surgical removal of ribs one to four. The appearance after the subtotal removal of ribs five and six is shown in *C*. Observe that for the first time a portion of the heart shadow can be seen to the left of the vertebral column. Note that recalcification is occurring along the periosteal beds of some of the ribs which have been removed.

Two and one-half years after the resection of all ribs except the twelfth, the entire right hemithorax remains completely collapsed (*D*). The heart is clearly visible. Recalcification in the rib beds is more advanced, and the contralateral lung contains no recognizable tuberculous lesions. The spine has curved somewhat

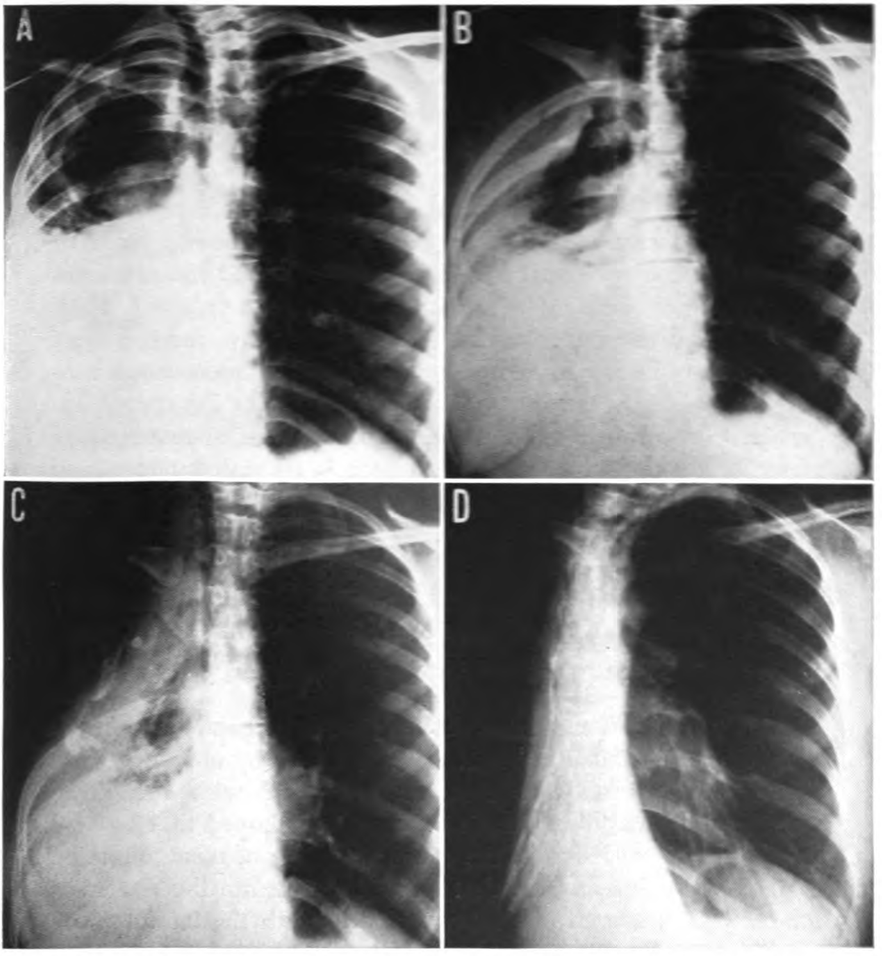


PLATE 53.—*A*, empyema complicating far-advanced tuberculosis, right. *B*, partial obliteration of right hemithorax by thoracoplasty, ribs 1–4. *C*, further collapse—ribs 5 and 6 resected. *D*, final result—11 rib thoracoplasty.

toward the unoperated side because the chest muscles on the right are now incapable of pulling against those on the left.

Although it is important for those who approach the study of pulmonary disease with the aid of radiologic methods to be conversant with the forms of therapeutic pulmonary collapse which formerly enjoyed a wide vogue, most of these methods have outlived their usefulness. Patients upon whom such procedures were carried out will continue to be found for many years to come, and it is important that the procedures and the purposes for which they were intended be known and remembered. They are still used to a much restricted extent but have for the most part been replaced by more dynamic surgical procedures rendered possible by the greatly increased safety of the direct approach to the thoracic cavity. The brilliant clinical response of many tuberculous lesions to treatment with streptomycin and the other nonsurgical agents in use today makes drastic surgery unnecessary for a considerable group of tuberculous patients. Lesions which are well localized, as well as those which are refractory to antibiotics and specific drugs, are more commonly treated by the method of lobectomy or segmental resection of the diseased part than by the more indirect method of chest wall collapse.

The student of medicine should seek to expand the lessons taught by the clinical material presented here by utilizing every available opportunity to familiarize himself with the x-ray manifestations of intrathoracic diseases. It is hoped that he will have been impressed with the extensive utility of roentgenologic methods in this field and that he will appreciate the necessity for correlating actual clinical experiences with the innumerable combinations of x-ray appearances which he may expect to encounter.

READING LIST

ALEXANDER, J.: *The Collapse Therapy of Pulmonary Tuberculosis* (Springfield, Ill.: Charles C Thomas, Publisher, 1937).

FORESTIER, J.: Roentgenological exploration of the bronchial tubes with iodized oil (lipiodol), Radiology 6:303, 1926.

GOOD, C. A., AND WILSON, T. W.: The solitary circumscribed pulmonary nodule: Study of seven hundred five cases encountered roentgenologi-

cally in a period of three and one half years, J.A.M.A. 166:210–215, Jan. 18, 1958.

HARRINGTON, S. W.: Value of roentgen rays in the diagnosis and surgical treatment of extrapulmonary intrathoracic tumors, Am. J. Roentgenol. 33:340–349, March, 1935.

HILLEBOE, H. E., AND MORGAN, R. H.: *Mass Radiography of the Chest* (Chicago: Year Book Publishers, Inc., 1945).

HINSHAW, H. C., AND GARLAND, L. H.: *Diseases of the Chest* (Philadelphia: W. B. Saunders Company, 1956).

HODGES, F. J.: Medical and economic advantages of roentgenographic chest survey of all hospital admissions, Ann. Int. Med. 9:1639–1657, June, 1936.

——: Differential diagnosis of non-specific interstitial pneumonitis, Radiology 34:276–282, March, 1940.

MANGES, W. F.: Non-opaque foreign bodies in the air passages, Brit. J. Radiol. April, 1926, p. 119.

POTTER, H. E.; DOUGLAS, B. H., AND BIRKELO, C. C.: Miniature x-ray chest film, Radiology 34:283–291, March, 1940.

RIGLER, L. G.: *The Chest: A Handbook of Roentgen Diagnosis* (2d ed.; Chicago: Year Book Publishers, Inc., 1954).

ROBBINS, L. L.: Mediastinal tumors, Radiology 43:115–121, August, 1944.

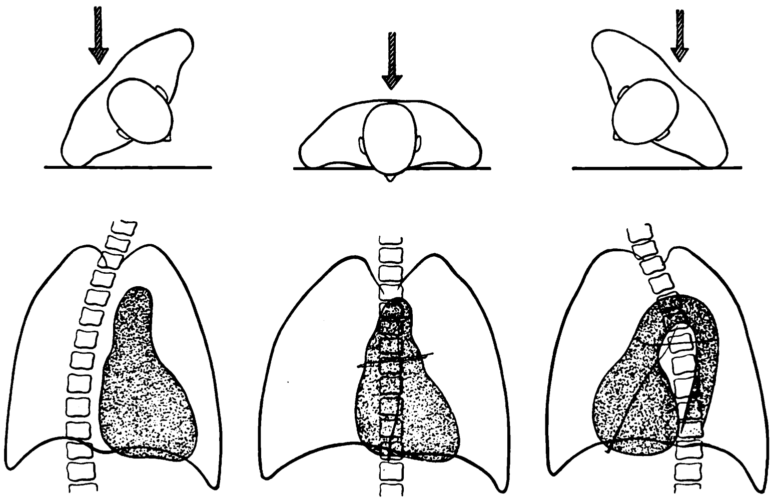
SHANKS, S. C., AND KERLEY, P. (ed.): *A Textbook of X-ray Diagnosis* (2d ed.; Philadelphia: W. B. Saunders Company, 1951), vol. II.

6

The Cardiovascular System

THE APPLICATIONS OF RADIOLOGY to cardiovascular diagnosis have been enormously increased in scope and importance since the introduction and practical application of new and ingenious technics. These enable observers to follow the course of the circulating blood through the chambers of the heart and all parts of the circulatory system. Not until the close of World War II did the newer methods, involving the addition of radiopaque substances to the blood stream, become popular and widely used in American medicine. During the present decade, diagnostic radiology has experienced greater and more vigorous growth in this than in any other field.

Prior to the advent and acceptance of the new dynamic cardiovascular technics, radiologists based their opinions regarding organic and functional cardiac disorders on observations concerning the size, position, shape, density and movements of the cardiac shadow. Most of their observations could be taken from chest roentgenograms made in standard positions—frontal, lateral and left and right anterior oblique (Plate 54). With slight additional effort, actual cardiac area and diameter measurements were available. Fluoroscopy was most helpful in determining the character of cardiac movements. Those old and simple methods are still serviceable; and, using the experience gained from more elaborate procedures, they have become even more useful in the detection and evaluation of circulatory disease.



Right Anterior Oblique | Frontal | Left Anterior Oblique

PLATE 54.—Explanation of commonly employed oblique projections of the chest. When the patient stands, facing the film, at an angle of 45 degrees with his *right* shoulder close to the film, the resulting exposure projects his spine to his right, his heart to his left. The situation is reversed if he stands with his *left* shoulder close to the film. Note how the standard oblique projections add to one's ability to observe the aorta. The right anterior oblique projection is better for recording the left bronchus and its branches in bronchography; the left anterior oblique projection is better for the right bronchus and its branches.

Plate 55 illustrates how conventional x-ray methods can be used to provide important information about the heart. The heart shown in *A* is so obviously oversized that actual measurement would seem to be superfluous. Detailed size measurements can be of value, however, when mild degrees of disproportion between heart size and body weight and height are suspected or to verify progressive increases or decreases of small magnitude. The great enlargement here shown is associated with multiple valvular defects, the result of earlier endocarditis. The moderate accentuation of pulmonary vascular markings throughout both lungs represents associated chronic passive congestion.

A much more spectacular condition is shown in Plate 55, *B*. What at first appeared to be great enlargement of the heart is shown, by pericardial aspiration and the introduction of air, to be pericarditis with effusion. Note that in the presence of air the residual pericardial fluid seeks and maintains a horizontal level. The same condition holds at the base of the *right* hemithorax, where pleural fluid has been removed in part and replaced with air.

The diagnostic value of altered cardiac shape is illustrated in Plate 55, *C*, which shows a heart in frontal and in lateral projection. This patient has mitral stenosis of sufficient degree to have resulted in selective enlargement of the left atrium. An abnormal bulge produced by the enlarged left auricular appendage can be seen on the left border of the cardiac silhouette, where normally the contour is slightly concave. Viewed in the direct lateral position, a similar, more prominent bulge in the posterior contour of the heart shadow protrudes almost to the anterior margins of the vertebrae; whereas the "retrocardiac space" is not encroached upon by any part of the heart under normal conditions. The localized posterior enlargement corresponds in position to the left atrium. When this combination of signs is observed, one can expect with confidence that auscultatory evidence of mitral stenosis will be demonstrable. Unfortunately, not all forms of valvular heart disease present such dependable or characteristic x-ray signs.

As seen in the lateral view, enlargement of the left ventricle narrows or obliterates the lower half of the retrocardiac space.

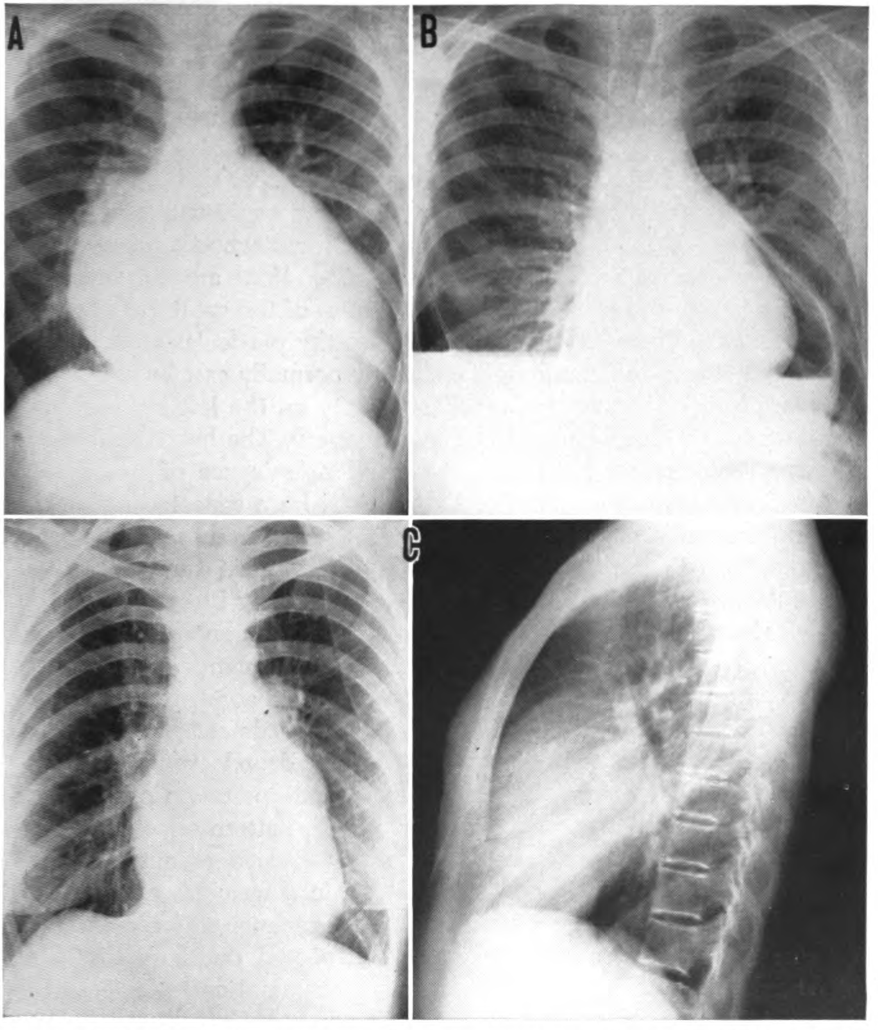


PLATE 55.—*A,* obvious cardiac enlargement; endocarditis with multiple valvular defects. *B,* pericarditis with effusion after aspiration and introduction of air. *C,* mitral stenosis, typical configuration, frontal and lateral projections.

The extent to which the heart lies in contact with the anterior chest wall, on the other hand, may be taken as a serviceable index of right ventricular enlargement.

The deposition of lime salts in the pericardium following active pericarditis and in chronically diseased cardiac valves and the rare discovery of metallic foreign bodies within cardiac chambers or embedded in the myocardium represent examples of the use of shadow density differences for diagnostic purposes.

Size, position, shape and density alterations are commonly and reliably associated with abnormalities of the great vessels as well as the heart. Plate 56, *A*, is noteworthy particularly because of the absence of the knoblike shadow normally cast by the left margin of the aortic arch. The convexity on the left represents the considerably enlarged pulmonary artery. The heart is somewhat enlarged and there is associated prominence of the pulmonary vessel shadows. These deviations from expected normal appearance strongly suggest congenital heart disease characterized by (1) hypoplasia or absence of the aortic arch, (2) a septal defect with left to right shunt, permitting blood from the left heart to enter the pulmonary circuit at abnormally high pressure, and perhaps (3) an unorthodox communication between the pulmonary artery and the deformed aorta. In this case the exact nature of the multiple structural defects was never proved, although the clinical history of profound cyanosis from birth certainly was in keeping with the interpretation of radiological findings. The great variability in the pattern of congenital malformations of the heart and great vessels does not permit accurate anatomical diagnosis in every instance; but, as a general rule, most examples of defective circulatory development can be recognized or intelligently suspected on the basis of standard radiographic and fluoroscopic examinations.

Atheroma of the thoracic aorta, when sufficiently far advanced, results in enlargement of caliber and increase in length, both of which changes are detectable on x-ray examination. Plate 56, *B*, shows a profound degree of elongation and tortuosity as seen in lateral projection. Not infrequently, deposits of calcium, when abundant, can be identified in this view and can be seen in frontal projection as a circlet of great density out-

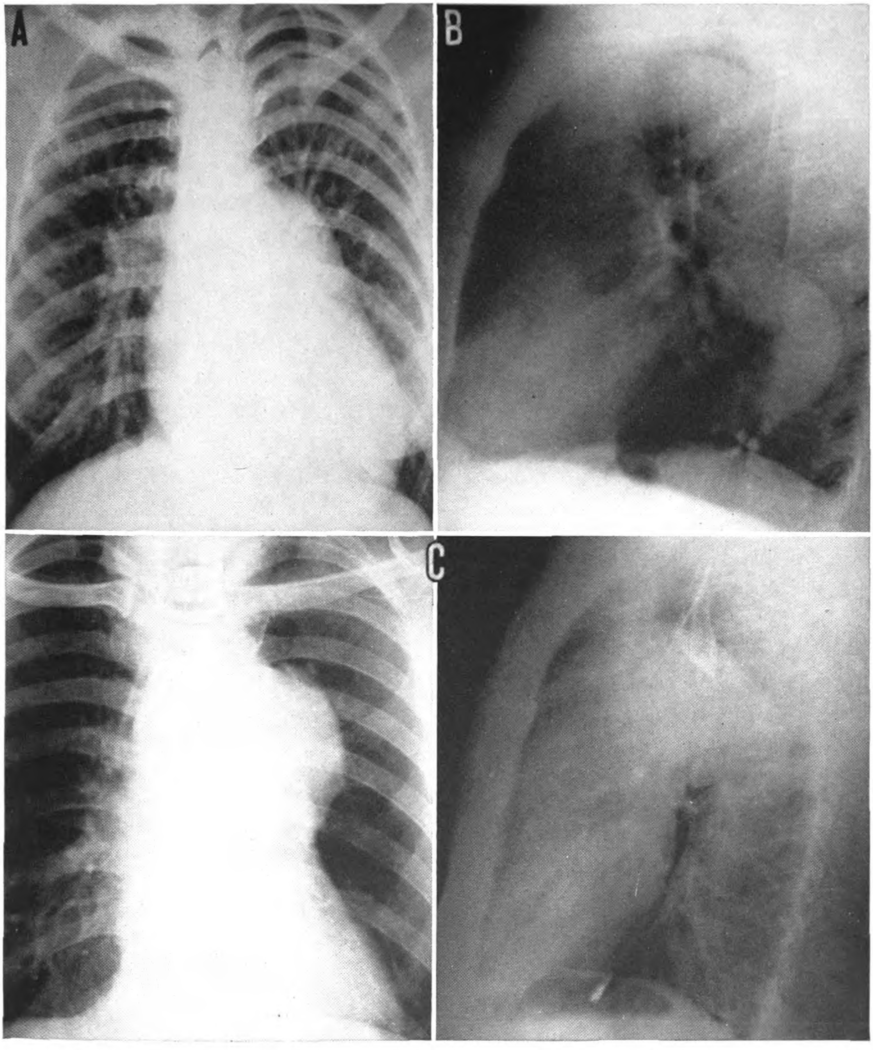


PLATE 56.—*A,* congenital heart disease, defective interauricular septum suspected. *B,* tortuous atheromatous aorta. *C,* fusiform aneurysm, ascending and proximal transverse segments of aorta, frontal and lateral projections.

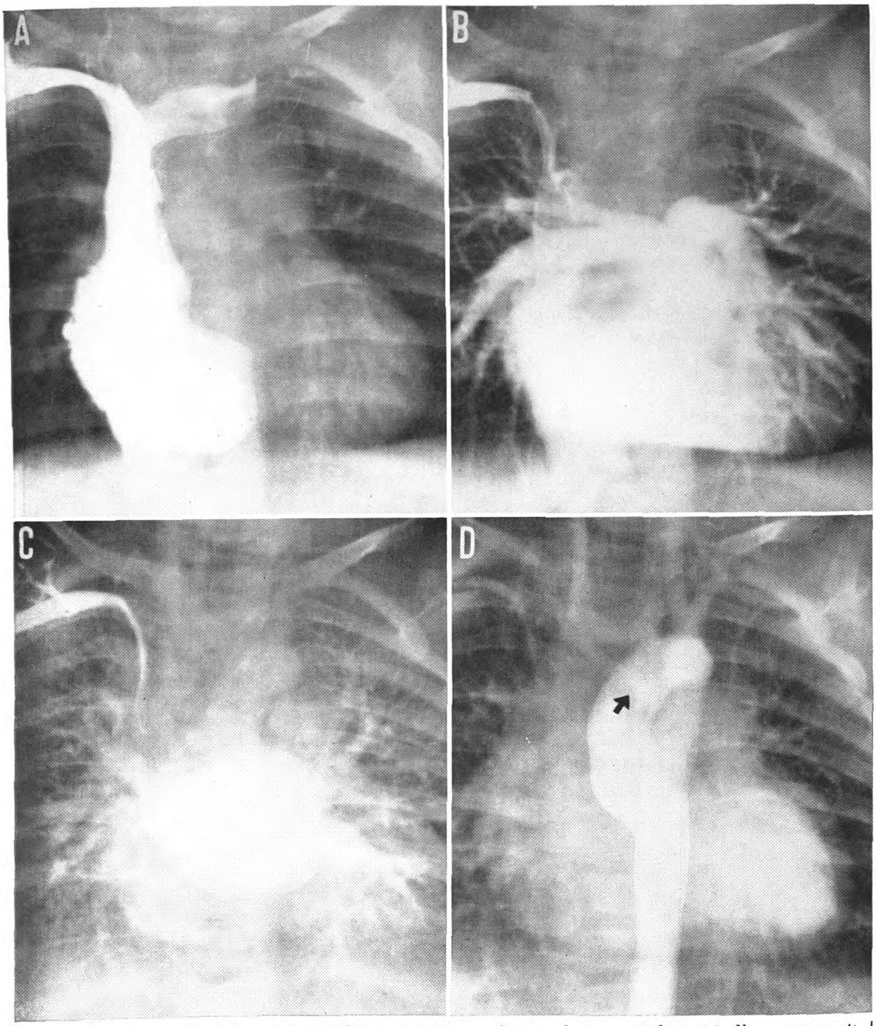


PLATE 57.—Normal angiocardiogram. In infant of 6 months, 16 lb., congenital heart disease was suspected, but routine venous angiocardiogram revealed no intracardiac defect; 8 cc. of 70% urokon® was rapidly injected into the right antecubital vein. Fleeting passage of the contrast medium was recorded on film every half-second with the child supine on an automatic serial filming device. *A*, contrast material streams down superior vena cava into right auricle filmed in diastolic phase. *B*, ½ second later, superior vena cava has virtually cleared. Right auricle in systole is emptying into right ventricle which lies in central part of heart. A previous contraction has filled the pulmonary artery and its branches. *C*, 2 seconds later, right heart

lining the aorta at the arch. Aortic tortuosity may be sufficiently pronounced to be visible as protrusions to one or both sides of the mediastinal shadow in frontal view. Erroneous interpretation can be avoided by utilizing lateral positioning.

Although at times aortic aneurysm is the simplest of lesions to recognize radiographically, it may be very difficult to exclude some form of mediastinal or neighboring pulmonary neoplasm as the cause of abnormal findings. Pulsation, typical expansile vascular pulsation, is by no means a constant feature on fluoroscopic examination. No aneurysm will pulsate visibly if its cavity is largely filled with an organized thrombus. Transmitted motion is so common in the case of tumors lying close to the aorta that pulsation should not be reported unless it is clear that opposite walls of the mass move away from each other during ventricular systole. If the shadow of the mass in question remains close to or indistinguishable from the aorta in all angles of projection, the presence of aneurysm is highly probable regardless of pulsation. Aneurysms of the ascending limb of the aorta present to the right in frontal view; the reverse is true of descending limb lesions. Plate 56, *C*, indicates how helpful it is to compare two views in a case of fusiform aneurysm of the ascending limb.

Over and beyond the impressions to be gained from the older, conventional methods, radiologists may now peer into the heart itself. Graphic demonstration of the various cardiac chambers and the great vessels in living patients is growing in practical usage. A wide variety of developmental defects—such as, aortic coarctation, tetralogy of Fallot, pulmonic stenosis of several varieties, transposition of the great vessels and septal defects, as well as many others—can be identified and evaluated with great precision. Cardiovascular radiology is advancing at a rapid pace, in step with cardiovascular surgery.

Venous angiocardiography is performed by introducing

---

has cleared of contrast material, which returns from lungs through pulmonary veins to fill left auricle. *D*, 3½ seconds later, left ventricle in full diastole; aorta, ascending in midline, arches and descends to left. Minor anomalous variation in branches is shown in origin of right subclavian artery (arrow) from descending aorta rather than from innominate artery.

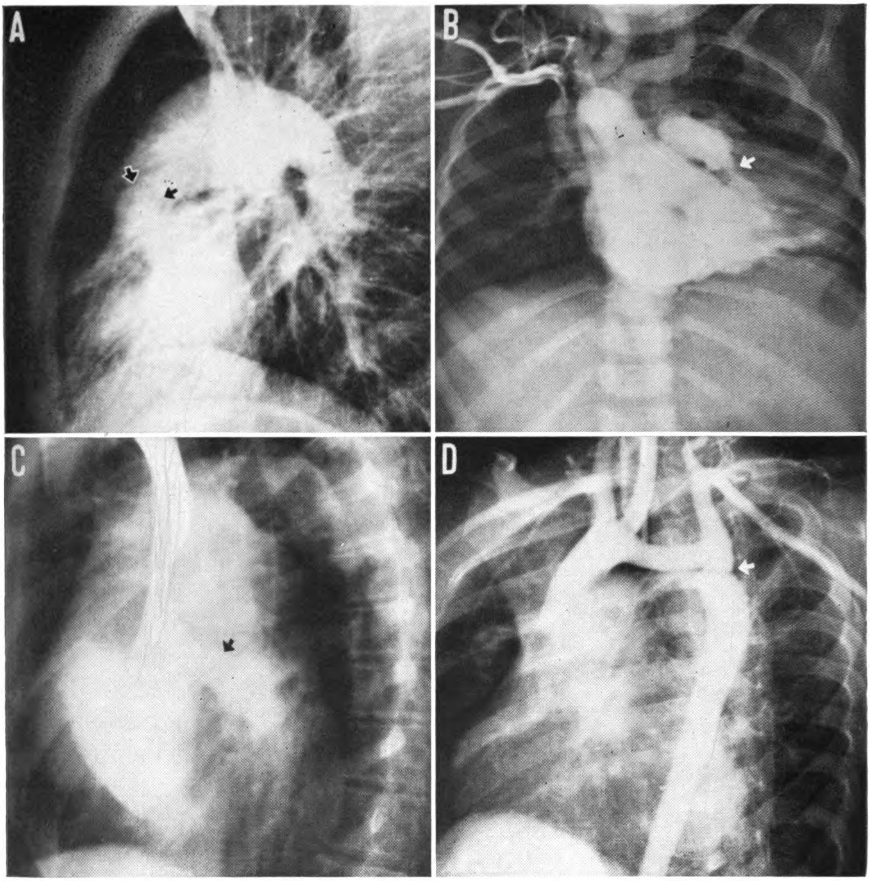


PLATE 58.—Angiocardiography in congenital heart disease. *A*, pulmonary valve stenosis, lateral view, with traces of contrast material outlining superior vena cava. Right auricle in diastole contrasts with right ventricle nearly empty in systole lying anterior to it. In base of dilated pulmonary artery, convex narrow band (arrows) is stenosed pulmonary valve thrust upward by ventricular contraction. Fusion of valve leaflets results in dome-shaped diaphragm, never seen in normal subject.

B, tetralogy of Fallot, frontal view. Superior vena cava nearly free from contrast, although traces remain in arm veins. Right auricle in diastole. As central-lying right ventricle contracts, contrast material enters both aorta and pulmonary artery. Channel to pulmonary artery is greatly narrowed—infundibular stenosis (arrow). As is often true in tetralogy, the aorta arches and descends on right with great vessels arising in mirror-image of normal. Left subclavian artery is congenitally stenosed and does not fill. Simultaneous filling of aorta and pulmonary artery from right ventricle together

opaque material at a rapid rate into a large peripheral vein and following its course from vena cava through the right heart, the pulmonary circuit, the left heart and out into the aorta and its major branches by means of multiple, closely spaced roentgenograms of the chest. The exposures must be of brief duration and must be made at a rate of 2–12 or more per second if maximum information is to be derived from the procedure (Plate 57 and Plate 58, *A, B* and *C*). The simultaneous recording of the electrocardiogram is imperative for the purpose of relating individual exposures to specific phases of the cardiac cycle. Simultaneous filming in two projections greatly enhances the value of results.

Selective angiocardiography calls for opaque injection at a predetermined point by way of a long cardiac catheter. Usually this follows multiple readings of oxygen saturation and pressure obtained during cardiac catheterization. By means of this technic it is possible to demonstrate in great detail the anatomical and physiological characteristics of a localized defect. The relationship of the aorta to the ventricular septal defect in tetralogy of Fallot is nicely shown by this method in Plate 59, *A* and *B*.

Aortography is carried out by x-ray examination of the aorta after opaque media has been introduced. This can be done by injection through a long needle plunged directly into the abdominal aorta from behind and the left below the ribs. Rapid serial filming is unnecessary; three or four exposures at intervals of several seconds are sufficient in most instances. Depending on

---

with some type of pulmonary stenosis indicates tetralogy of Fallot.

C, auricular septal defect. This first film of angiocardiographic series shows right auricle filling from superior vena cava. Stream of contrast medium (arrow) directed posteriorly is passing through an auricular septal defect to fill left auricle. This right-to-left shunt caused cyanosis. Associated severe pulmonary hypertension was demonstrated at cardiac catheterization.

D, coarctation of aorta and patent ductus arteriosus. Thoracic aortogram was made by rapid injection of contrast material retrograde into proximal part of left carotid artery (overlying intratracheal tube). Distal aortic arch is elongated, left subclavian artery is slightly enlarged and, immediately below this, a narrow, incomplete constriction—coarctation—is seen (arrow). Just opposite coarctation, an anteriorly directed stream of contrast medium identifies a 5 mm. diameter patent ductus arteriosus. Note slight poststenotic dilatation of aorta and scant collateral circulation.

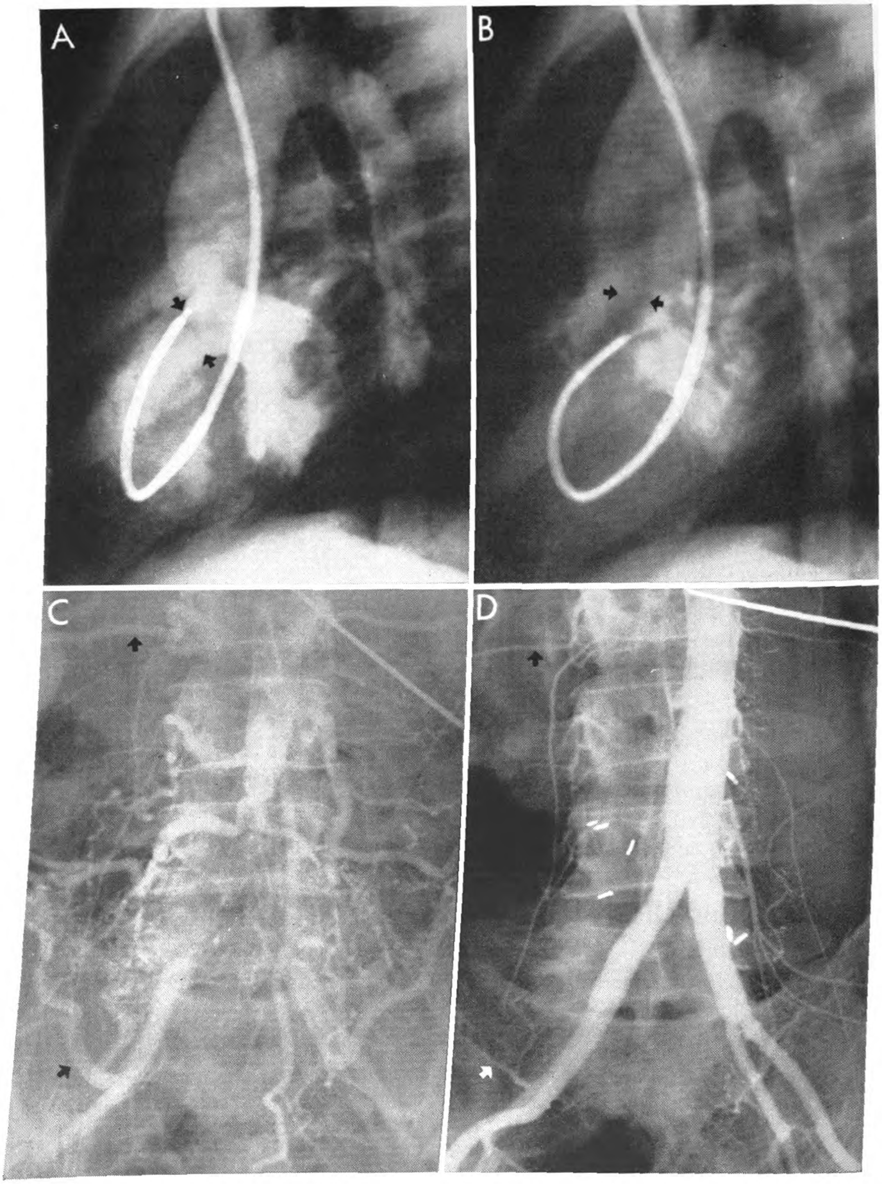


PLATE 59.—*A* and *B*, individual exposures from a selective angiographic series in case of tetralogy of Fallot in 3 year old boy. Catheter tip lies in the high inter-

the injection level selected, the method can be used to demonstrate the status of various segments of the abdominal aorta and its branches. In the case of patients with Leriche syndrome, it is particularly useful to determine the location and extent of obstructive arterial disease (Plate 59, *C* and *D*); also in the study of renal lesions (Plate 77, *B*, p. 255). The arch of the aorta and the descending limb within the thorax can be identified late in the course of angiocardiographic filming although dilution of the opaque material is usually great. Better, more vivid images can be obtained by retrograde injection by way of a catheter introduced into a peripheral artery and passed in retrograde manner toward the point of origin of the aorta. This is known as retrograde aortography (Plate 58, *D*).

By means of appropriate injections, peripheral arteries and veins can be studied by the radiologist. Such situations as arteriovenous aneurysms, occlusive arteriosclerosis and vascular neoplasms lend themselves well to this diagnostic approach (Plate 60, *A* and *B*).

The very useful procedure of intracranial angiography has been described and illustrated in Chapter 3.

For the particular study of the mitral valve region, direct injection of the left atrium and the left ventricle can be employed with safety and to great advantage.

Important and ordinarily obscure abnormalities of the splenic vein and the portal system can be explored effectively by means of splenoportography. Opaque material is introduced into the splenic pulp by means of direct puncture and followed by several film exposures of the upper abdomen to record the speed and the manner in which the material moves toward the right heart. Hypertension within the splenic or portal veins is dramatically demonstrated (Plate 60, *D*), and sometimes tumors of the pancreas and lesions within the liver can be demonstrated.

---

ventricular septal defect. *A* shows the broad communication between the ventricles in diastole (arrows). During ventricular systole (*B*) a column of nonopacified blood pours into the overriding aorta (arrows).

C and *D*, abdominal aortograms before (*C*) and after (*D*) endarterectomy to re-establish blood flow through an extensive segment of vascular occlusion. Circulation to the lower extremities had depended on extensive collateral circulation.

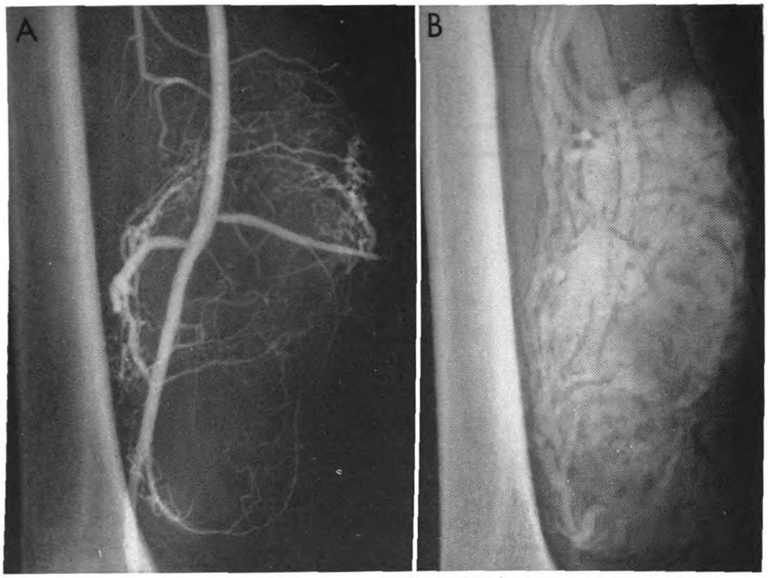


PLATE 60.—*A* and *B*, femoral arteriograms demonstrating the arterial phase (*A*) and the capillary and venous phase (*B*) of circulation within a spindle cell sarcoma of the thigh. This type of examination provides clear differentiation from aneurysm, which had been suspected clinically *(continued).*

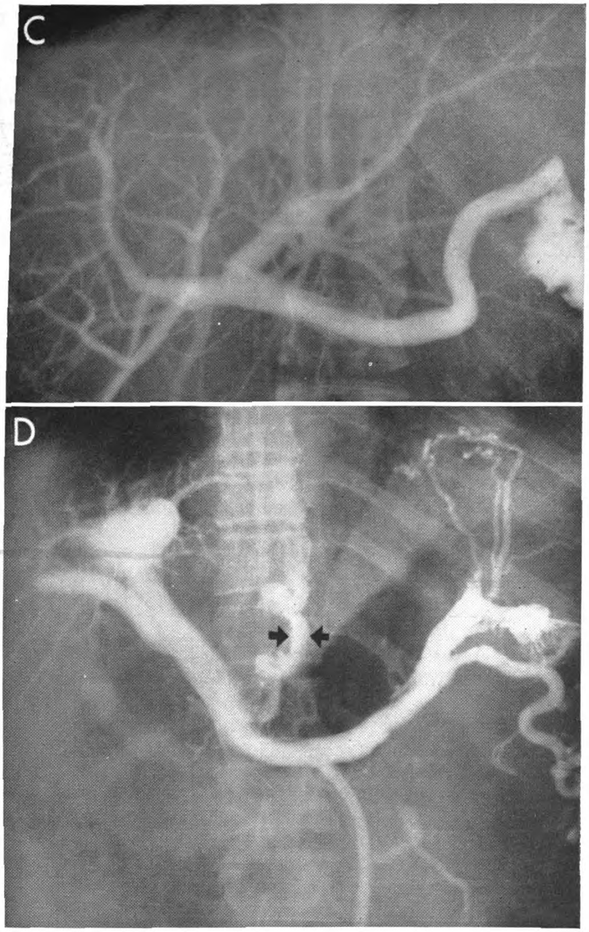


PLATE 60 *(cont.)*—*C*, normal splenoportogram following introduction of dense opaque fluid into the splenic pulp. Blood flows freely from the spleen via the splenic and portal channels within the liver.

D, an example of greatly altered venous now in a patient with severe cirrhosis. Note the greatly deformed vessels in the liver and esophageal varices supplied by the coronary vein (arrows).

Further advances and wider interest in cardiovascular radiology are to be expected in the years immediately ahead. More perfect image-amplifying apparatus than is presently available seems certain to be in the relatively near offing. If and when such equipment has been developed, truly slow-motion cinematography can be employed without the risk of excessive patient exposure. The teaching of circulatory dynamics should be enormously enhanced through the preparation and display of x-ray movies.

READING LIST

DOTTER, C. T., AND STEINBERG, I.: *Annals of Roentgenology-Angiocardiography* (New York: Paul B. Hoeber, Inc., 1951), vol. 20.

FIGLEY, M. M.: The expanding scope of cardiovascular radiology, Am. J. Roentgenol. 76:721–729, October, 1956.

——; FRY, W. J.; OREBAUGH, J. E., AND POLLARD, H. M.: Percutaneous splenoportography, Gastroenterology 28:153–162, February, 1955.

HODGES, F. J.: The growing importance of cardiovascular radiology, New England J. Med. 255:28–35, July 5, 1956.

JÖNSSON, G.: Selective angiography and thoracic aortography, in MCCLAREN, J. W. (ed.): *Modern Trends in Diagnostic Radiology,* 2d series (New York: Paul B. Hoeber, Inc., 1953).

KAPLAN, H. S., AND ROBINSON, S. J.: *Congenital Heart Disease: An Illustrated Diagnostic Approach* (New York: McGraw-Hill Book Company, Inc., 1954).

KJELLBERG, S. R.; MANNHEIMER, E.; RUDHE, U., AND JÖNSSON, B.: *Diagnosis of Congenital Heart Disease* (Chicago: Year Book Publishers, Inc., 1955).

LERICHE, R.; BEACONSFIELD, P., AND BOELY, C.: Aortography: Its interpretation and value: report of 200 cases. Surg., Gynec. & Obst. 94:83–90, 1952.

NEUHAUSER, E. B. D.: Roentgen diagnosis of double aortic arch and other anomalies of the great vessels, Am. J. Roentgenol. 56:1–12, July, 1946.

7

The Gastrointestinal Tract

EXPRESSED IN TERMS of patient volume, the gastrointestinal examinations carried out by the x-ray service of a general hospital represent no more than 20 per cent of the diagnostic work load[1]. In the time and effort involved, however, this phase of diagnostic roentgenology assumes much more imposing proportions. The time devoted to fluoroscopy, which this type of examination requires, limits the volume of cases for gastrointestinal diagnosis which can be carried out with acceptable accuracy and completeness.

It is not to be expected that medical students will concern themselves with the technics and skills of gastrointestinal fluoroscopy, an activity which requires broad training in clinical medicine and long practice and close attention to details of procedure, but it is important that they realize how much the ultimate solution of diagnostic problems involving the alimentary tract depends on enlightened fluoroscopic observation. Following all the established rules that govern its proper use, the radiologist uses his fluoroscope to scrutinize various parts of the gastrointestinal tract before, during and after the introduction of contrast materials into the lumen of the alimentary tube or into related sinus tracts. From direct observation much can be learned about the behavior of these animated structures which

(1) In the 25 years, 1932–57, 170,173 gastrointestinal examinations were performed. This represents 16 per cent of the 1,033,058 patient-visits for x-ray diagnosis during that period at University Hospital.

may be entirely lost in still photographic images. Under fluoroscopic control, cursory search for signs of abnormality enables the examiner to determine the type of filming procedure that will be most apt to provide the greatest assistance in analyzing the situation in any individual case. Screen examination often leads to recognition of abnormality which would otherwise escape detection. An experienced fluoroscopist, if forced to choose between screen observations and films in examining patients for suspected gastrointestinal disorder, would almost certainly elect the former, so very important are these observations. Better still, of course, is the combination of both methods of study, and the roentgenograms offer the additional advantage of providing a permanent visual record of the condition.

It is well to remember that sound x-ray diagnosis in the gastrointestinal field rests on careful integration of fluoroscopic and radiographic evidence and, further, that fluoroscopic examinations vary in reliability with the expertness of the observer. It is a common mistake among patients, and unfortunately among many physicians as well, to assume that any and all derangements within the body are simply and unequivocally recognizable to anyone who goes through the motions of making a fluoroscopic examination. Nothing could be farther from the truth. In the gastrointestinal tract in particular, fluoroscopic examination is difficult, painstaking work that requires skill, long experience and unrelenting diligence if dependable results are to be achieved.

Bearing in mind the importance of fluoroscopic procedures, let us consider the various ways in which x-ray methods can help to unravel the knotty problems which confront the physician who is consulted by patients with various complaints related to the gastrointestinal tract. By the use of carefully selected roentgenograms for illustrative material, it should be possible to convey some idea of the utility of radiologic procedures in evaluating the status of such patients.

For the sake of clarity and simplicity, it is helpful to think of problems in x-ray diagnosis in terms of broad anatomic regions which in the digestive tract extend from the pharynx to the perineum. The gastrointestinal tract may be considered as broken

down into five convenient subdivisions within which are segregated more or less closely related conditions. These five fields of interest are:

Esophagus
Stomach and small intestine
Biliary tract
Large intestine
Abdomen generally

It should be mentioned that any x-ray examination which involves the digestive tract can be affected materially by the advance preparation of the patient. In general, the best results are obtained when the alimentary tube is completely empty at the outset. The active co-operation of the referring physician, as well as the patient, is mandatory if the examination is to provide reliable information. Diagnostic errors are to be expected when the preparation is slighted. Hasty, ill-conceived attempts to use diagnostic short cuts all too frequently yield inconclusive, if not frankly deceptive, findings and therefore are to be condemned. In this field of x-ray diagnosis the false sense of security engendered by slipshod and entirely inadequate methods of examination can, and does, lead to tragic situations which are all the more pitiful because they are largely avoidable. It is poor practice to limit examination to a single part or division of the alimentary tract, because the symptomatology of gastrointestinal diseases is not sufficiently definitive to permit one to determine in advance which region, if any, will show tangible evidences of abnormality. Thorough investigation from esophagus to anus requires time, and every attempt to compress the procedure inevitably impairs the quality of the results. This the patient, the referring physician and the radiologist must recognize and accept.

THE ESOPHAGUS

The variety of abnormalities encountered in the esophagus in the course of a radiologist's experience is not great, particularly in comparison with other parts of the alimentary tract. When, however, the normal performance of the esophagus in

transmitting ingested materials from the pharynx to the stomach is in any way modified, the appearance at the fluoroscope is apt to be spectacular. Ordinarily, opaque material swallowed by the patient is quickly propelled to the stomach with or without the aid of gravity. Rapid emptying is so characteristic of the esophagus that the reproduction of the normal esophagus in films is difficult. By observing the esophagus during deglutition it is possible to learn much about neighboring mediastinal structures. The imprint of the transverse aorta is clearly recognizable; and, when viewed in lateral projection, the opaquely filled lumen of the esophagus serves to locate the posterior margin of the heart. Observed deviation to right or left often helps to determine the nature of abnormalities that involve the lungs.

At the very origin of the esophagus, at the level of the sixth cervical vertebra, a point of structural weakness in the posterior wall sometimes leads to sacculation under the stress of pressures produced during the act of swallowing. Pulsion diverticula originating at this retropharyngeal point sometimes become large and, in so doing, progressively obstruct the normal lumen; this in turn is conducive to further distention of the accessory sac.

Diverticula elsewhere along the course of the esophagus occur most frequently near the midpoint, just below the aorta, close to the level of the tracheal bifurcation. Supposedly, these originate in association with extra-esophageal inflammations followed by scar tissue contracture, but it does not seem probable that they can properly be called traction diverticula in every instance. Bulging as the result of internally applied pressure in the presence of partial obstruction may well account for their development. It is not uncommon to observe that such diverticula vary in size from moment to moment during screen examination.

A sizable diverticulum located at an unusual point a short distance above the diaphragm is shown in Plate 61, *A*. It would appear that the muscle coats at the lower terminus of the esophagus were strongly contracted to account for mild dilatation of the entire tube, and this perhaps sets the stage for the production of the accessory pouch. In most instances, diverticula along the middle and lower thirds of the esophagus are not responsible for clinical symptoms but are encountered as incidental findings.

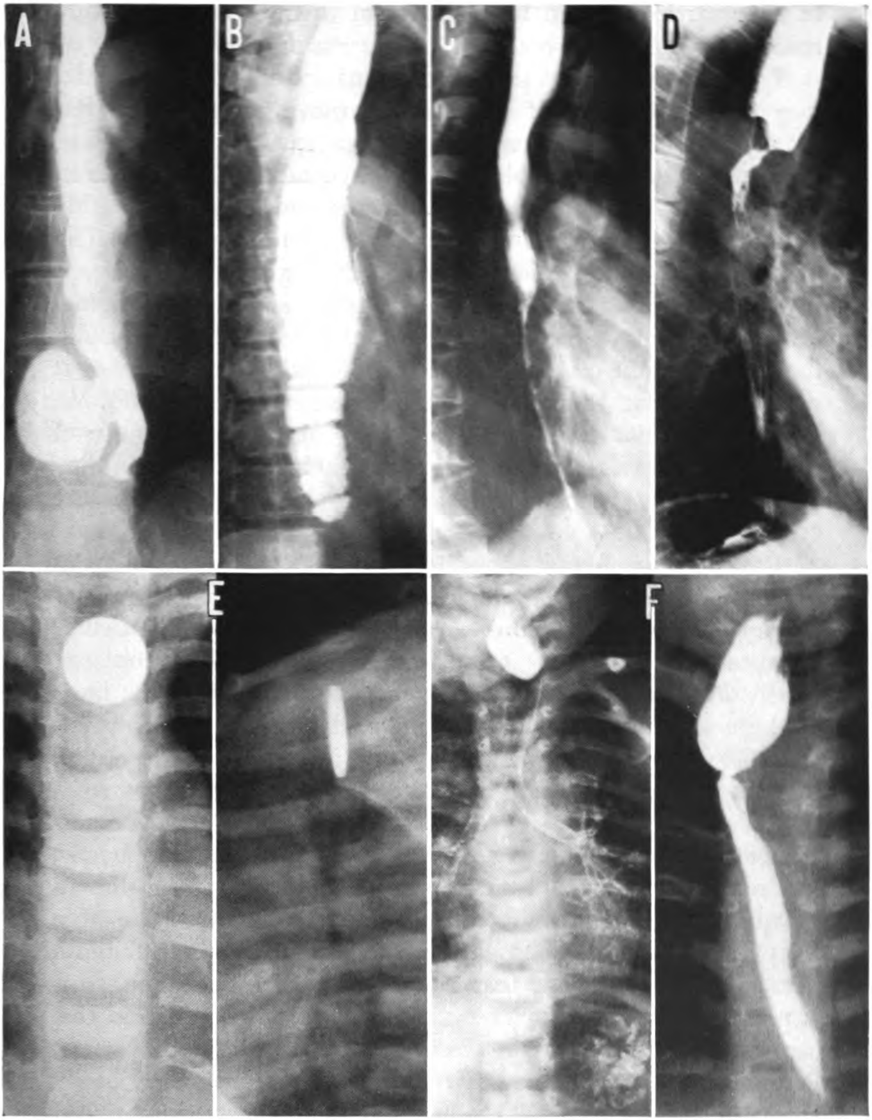


PLATE 61.—*A,* diverticulum. *B,* cardiospasm. *C,* postinflammatory stricture. *D,* primary carcinoma. *E,* foreign body (coin), frontal and lateral views. *F,* congenital atresia, before and after surgery.

In this particular case low substernal distress was effectively relieved by surgical resection of the diverticulum.

Prolonged intermittent or continuous spasm of the musculature of the esophagus at the diaphragm level, known as cardiospasm, produces such symptoms as dysphagia, regurgitation and substernal distress. Radiologically, this condition is recognized by marked distention of the esophagus and by the smoothly tapered ~~narrowing of the~~ lower end, which is characteristic. The example reproduced in Plate 61, *B,* although characteristic, is by no means as spectacular as many which may be seen. Sometimes, in the examination of chest films, one fails to consider the accumulation of food and secretions within the esophagus when attempting to explain bizarre enlargement and distortion of the mediastinal shadow. The feeding of a small quantity of some opaque material quickly explains such shadows when they are caused by tremendous distention and tortuosity of the esophagus.

Persistent, profound narrowing of the esophageal lumen, as shown in Plate 61, *C,* is seen occasionally as the result of inflammatory disease affecting the walls of the organ. In this particular instance the symptoms strongly suggested intrinsic neoplasm, which diagnosis could be disproved unequivocally on the basis of the x-ray appearance. Narrowing such as this commonly follows the ingestion of some excoriating fluid—in this case Lysol solution which the patient drank with suicidal intent.

Plate 61, *D,* was selected to demonstrate the most characteristic features of primary malignant tumor of the esophagus. When primary malignant tumors of other segments of the alimentary tract are discussed, it will be found that the most reliable x-ray signs of such lesions are entirely comparable with those demonstrated here. Note that the lumen of the upper esophagus is plumply filled with opaque material to a point which in this case almost coincides with the shadow of the transverse aorta. Pressure of the aorta, when it affects the esophagus, is easily recognized, because the curved contour of the aorta is imprinted upon the barium column. Here in striking fashion the lumen of the esophagus is abruptly narrowed. The greatly reduced stream of opaque material is tortuous and its margins are rag-

ged. Viewed in several projections, the narrowed segment will be found to be eccentrically placed with respect to the uninvolved portion. The edges of the barium column seem to overhang the narrowed segment. It is difficult to determine with certainty the lowermost point of the lesion which encircles the esophagus, for it is not possible to maintain complete filling of the normal part through the slender channel which is surrounded by tumor tissue. Primary tumors of the alimentary tube are commonly annular in form when first seen, and it is axiomatic that they are relatively short. In this case the tumor appears to end near the lower margin of the transverse aorta, which indicates that it is no more than 3 or 4 cm. in length.

The ingestion of foreign bodies, particularly by small children, is not an uncommon occurrence. In most instances objects small enough to be accepted by the esophagus pass spontaneously into the stomach and from there through the entire alimentary tract. However, this is not always the case. The lumen of the esophagus is slightly broader just above the aorta, and it is common for foreign bodies to become lodged at this point. Plate 61, *E,* shows the dense shadow cast by a coin lying in the esophagus at this level. By its position one can tell with certainty whether a foreign body has been swallowed or aspirated (often a matter of concern and uncertainty to the clinician who refers the patient to the radiologist). If it lies within the thorax with its plane of greatest diameter parallel to the anterior surface of the body, as is nicely shown in these two illustrations, one can be sure that it is in the esophagus, because it is easier for the esophagus to accommodate it in that plane. In lateral view, as further proof, the air-filled trachea can be identified anterior to the coin. Similar objects in the trachea are turned to lie in the sagittal plane, because the only distensible portion of the tracheal walls is found posteriorly.

An example of congenital fault is shown in the esophageal roentgenograms pictured in Plate 61, *F.* The first of these represents the appearance after a small amount of iodized oil was administered to a newborn child who had regurgitated all feedings. Note the pouch of dense material which lies at the clavicular level, the faint tracery of opaque oil which represents leakage

into the bronchial tree by way of the larynx during ingestion efforts, the presence of air and a very little oil in the stomach and the air-filling of intestine. All these features help to explain the congenital defect which was postulated on x-ray evidence and then confirmed and corrected surgically. The upper part of the esophagus ended in a blind pouch, as shown; its lower portion, entirely disconnected from the upper segment, communicated with the lower trachea and thus permitted air and oil to reach the abdominal viscera. The second illustration shows the results of surgical reconstruction.

THE STOMACH AND SMALL INTESTINE

Great individual variations are found in the roentgenologic appearance of the normal stomach. These differences, for the most part related to the habitus of the patient, are further dependent on the amount of barium suspension administered. In obese persons, owing to fat deposits which thicken the omentum and mesentery, the stomach is displaced upward to a horizontal position beneath the diaphragm. In hypersthenic patients with deep, broad chests and powerful abdominal musculature much the same situation is found. Plate 62, *A*, illustrates a high, transverse stomach to good advantage. Cholecystography preceded examination of the stomach, and the gallbladder, still filled with opaque material concentrated by the liver, is seen to have migrated upward along with the stomach. The third portion of the duodenum, effectively fixed by its peritoneal attachments, is in the position usually described in anatomy textbooks.

Many patients in whom no tangible evidence of abnormality can be demonstrated have stomachs which are largely vertical in position with the most dependent portion of the organ extending below the level of the iliac crests (Plate 62, *B*). Usually these patients are of asthenic habitus. When too much emphasis has been attached to this condition by someone who has conducted an x-ray examination, the patient is apt to volunteer the information that he has a "dropped stomach." This he assumes to be a grievous physical defect responsible for all manner of elusive ills. Actually, stomachs which occupy this position are

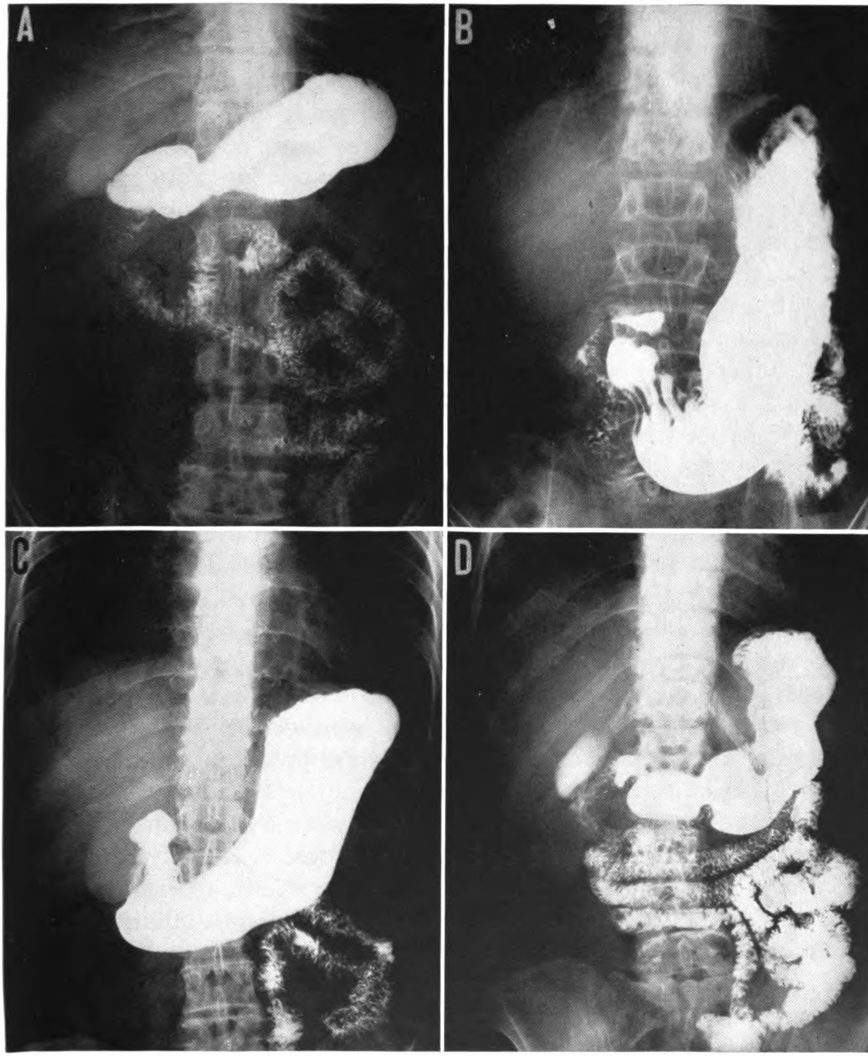


PLATE 62.—Four examples of normal stomach, showing common variations in position and tone.

able to function perfectly well, and patients should not be encouraged to think otherwise. In the instance illustrated, the duodenal first portion, or "bulb," is flattened, presumably by the gallbladder. Since it contains no opaque material, the gallbladder itself cannot be seen in this film.

The depth and rapidity of peristaltic contractions vary greatly under normal conditions. The introduction of food and manual palpation usually stimulate an otherwise quiescent stomach to develop active peristaltic movements. It is difficult to judge what is to be considered "hyperperistalsis" unless there is an associated obstruction at the pyloric outlet, and it is well to remember that normal variability has wide limits. Plate 62, *C*, shows a stomach with inconspicuous shallow peristaltic wave along its greater curvature. Again the gallbladder can be seen indenting the stomach close to the pyloric canal.

In *D*, four peristaltic waves can be seen. As the waves approach the pylorus they become deeper. In this instance the stomach has been filmed during very active peristalsis. Note, in passing, that the duodenum is hidden in part as it passes posterior to the stomach. During fluoroscopic examination it is necessary to rotate the patient and to use manual palpation to bring all parts of the duodenum into view. Although lesions are not common in the third portion, their presence must be suspected until definitely disproved, whenever the upper gastrointestinal tract is examined.

Peptic ulcer is more common in the duodenum than in the stomach in the ratio of 4 or 5 to 1; as a rule it is easily recognizable when found in the stomach. Paradoxically, ulcers which are not at once visible when opaque material is administered under fluoroscopic control may be extremely difficult to find. Most gastric ulcers occur along the posterior wall aspect of the lesser curvature, the commonest site being at or near the midpoint. In this location they are seen as obvious pockets protruding from the shadow of the body of the stomach. If the crater is filled with food residue, secretions or clotted blood at the time of examination, the full extent of the defect in the gastric wall may not be apparent. If, in frontal projection, the ulcer lies some little distance from the contour of the stomach,

rotation of the patient will be necessary to throw its shadow into silhouette. Ordinarily, patients complain of point tenderness when digital pressure is applied directly over a gastric ulcer. The ulcer shown in four successive exposures on one large film to prove the constancy of the defect (Plate 63, *A*) is located unusually high on the lesser curvature. Lesions in this position are often difficult to demonstrate because the cardiac portion of the stomach, which lies far posteriorly beneath the diaphragm, may cast its shadow over the margin of the lesser curvature unless the patient is advantageously positioned. Overlying ribs and costal cartilages at this level largely defeat efforts to palpate the region effectively. It is not difficult to be guilty of errors of omission when examining the uppermost part of the stomach. The particular ulcer shown here is quite characteristic except for its high position. Note the depressions in the stomach contour directly above and below the barium-filled crater. These represent the mounded ridge of inflamed stomach wall which surrounds the crater.

An ulcer occupying the classic position at the midpoint of the lesser curvature is shown in Plate 63, *B*. Here again, multiple exposures in rapid succession have been used to prove that the defect in the stomach contour is constant. Sometimes circular muscle spasm excited by the effect of the ulcer on the intrinsic nervous mechanism produces a deep indentation or "incisura" at a point on the greater curvature directly opposite the crater. At one time the incisura was described as one of the cardinal signs of gastric ulcer, but experience shows that it is by no means constant, although on occasion it is most helpful in pointing to an extremely small crater which might otherwise have escaped notice.

Even though there may be no obvious protrusion along the lesser curvature, an ulcer of considerable size may be present. It is for this reason that dexterous palpation under fluoroscopic control is so important to effective radiologic examination of the stomach. The examiner attempts to apply sufficient pressure to the abdominal wall to bring the mucosal pattern of the stomach into view by partial displacement of the barium. This maneuver is impossible in many instances, owing to the patient's obesity,

but the same effect can be approximated by observing peristalsis with the patient lying prone. A great deal can be learned concerning the mucosal surface of the gastric lumen if, at the outset of the fluoroscopic examination, the observer is alert to the necessity of watching the advancing barium stream when first it reaches the stomach. Any deviation from the usual appearance of the mucosal folds, however slight, draws the attention of the trained observer, causing him to use every means at his disposal to study the area in question more completely. In Plate 63, *C*, four exposures of a stomach are presented to show the great advantage of employing external pressure. Here, a sizable ulcer crater on the posterior wall has been brought into view. Although the lesion has been recognized at the fluoroscope, standard projections gave no indication of its presence. In these illustrations the observer is looking directly into the mouth of the large crater which is represented as a dense pool of barium trapped in the ulcer while the anterior and posterior walls of the stomach were approximated by externally applied pressure.

Gastric ulcer, although most commonly situated along the lesser curvature and the posterior wall in the middle third of the organ, may be found almost anywhere within the stomach. An ulcer of modest size located close to the pyloric canal is shown in Plate 63, *D*. Some writers suggest that ulcers found within 3 or 4 cm. of the pyloric ring will be malignant in a high percentage of cases. This belief is not well substantiated by actual experience. Obviously, ulcers which occur in the narrow part of the gastric lumen close to the gastric outlet can easily produce pyloric obstruction if there is sufficient associated inflammatory swelling. That situation does not obtain in the lesion shown here.

The rapidity with which large ulcerations of the mucosa are able to heal under favorable conditions is nothing short of spectacular. Although it is true that in some patients this proclivity is not apparent, there is every reason to expect that any gastric ulcer, however large, will respond to intensive medical management by progressive decrease in size to the point of complete disappearance within 10 days to three weeks. Un-

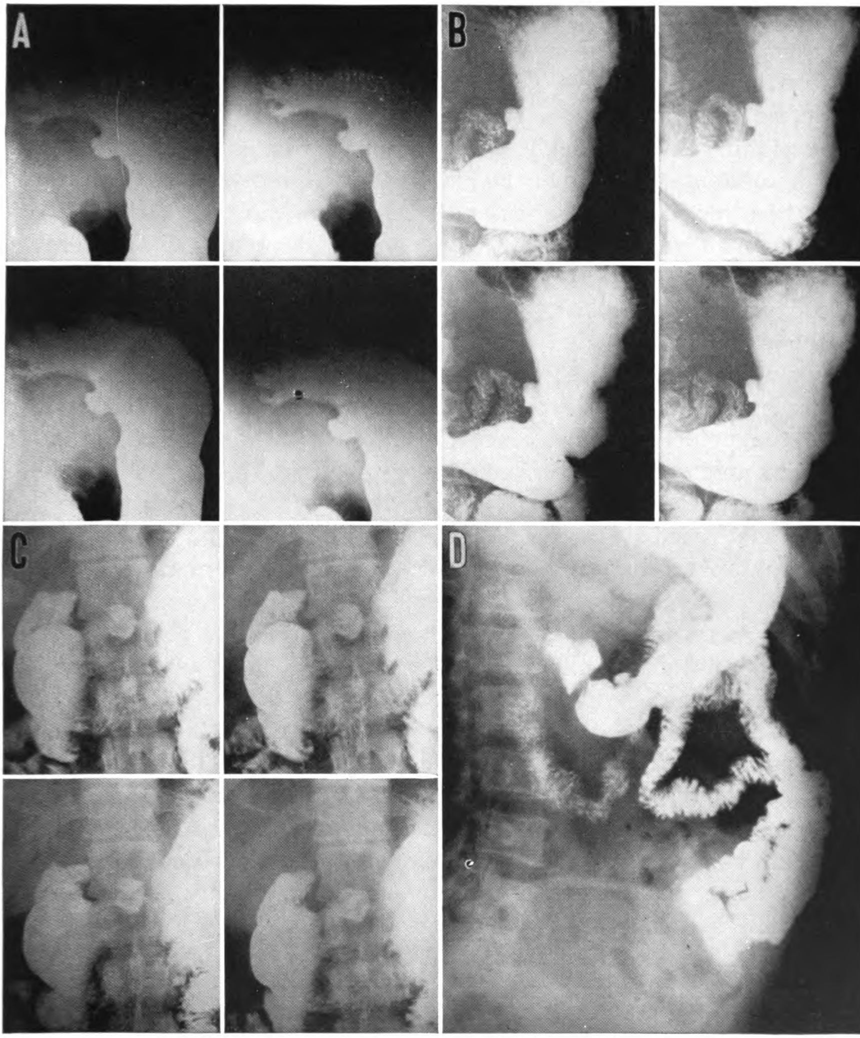


PLATE 63.—*A,* gastric ulcer crater, upper portion of lesser curvature. *B,* ulcer near middle of lesser curvature. *C,* crater of posterior wall ulcer, shown by compression. *D,* ulcer crater close to pyloric canal.

doubtedly a number of factors, such as the chronicity of the lesion, the strictness of the treatment regimen and the degree to which the patient co-operates, will figure importantly in determining the rate of healing, but in general benign gastric ulcers disappear quickly when properly treated. The patient whose stomach is shown in Plate 64 was discovered to have a large ulcer high on the lesser curvature on Mar. 25, 1941 (*A*). Ulcer management was instituted, and 24 days later the size of the ulcer crater was greatly reduced (*B*). Shortly thereafter the patient was allowed to continue treatment at home, with the understanding that he would return for observation. Seen again in the x-ray department on June 27, three months after his lesion was first discovered, the ulcer, reduced in size almost to the point of disappearance, could still be demonstrated as a tiny mucosal defect surrounded by radiating ridges of puckered muscosa (*C*). It is probable that the complete healing shown 14 months later (*D*) could have been accomplished somewhat more rapidly had the treatment program been more closely supervised under hospital conditions.

Primary neoplasms of the stomach are about as common as benign ulcers. Of all malignant neoplasms, those which arise in the alimentary tract predominate, and in the gastrointestinal tract the stomach is the most common point of origin. Less than 5 per cent of primary gastric carcinomas originate as peptic ulcers. Except for certain more or less reliable x-ray features which are not discussed here, malignant ulcers are recognized by their failure to heal with normal promptness under treatment. All gastric ulcers which are unduly refractory should be considered malignant and so treated.

By all means the commonest expression of primary gastric carcinoma consists of an irregular, circumscribed and constant defect in the shadow contours of the barium within the gastric lumen. Such defects are produced by the protrusion of neoplastic tissue into the lumen with the resultant replacement of opaque material by radiolucent tumor. Secondary ulceration within the tumor mass is commonplace, and such ulcers often are recognizable roentgenographically and may even be the outstanding feature. As in other parts of the alimentary tube,

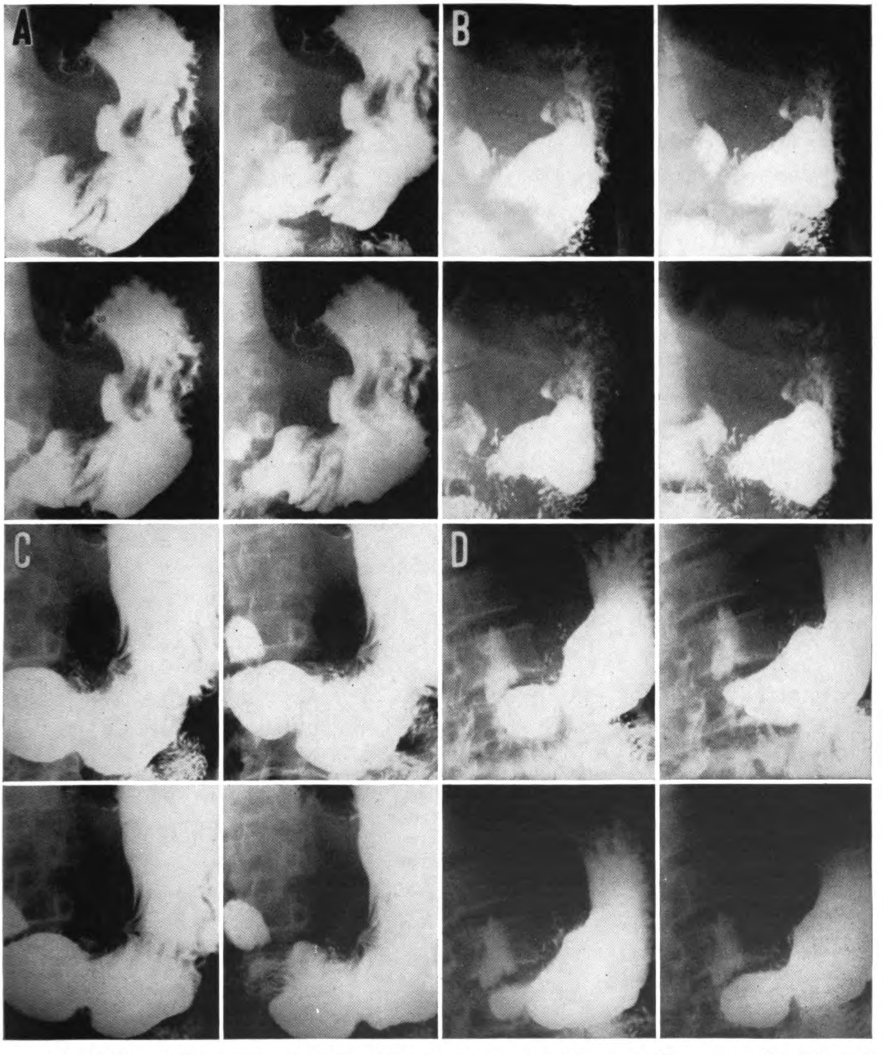


PLATE 64.—*A,* large gastric ulcer before treatment. *B,* same ulcer, greatly reduced after 24 days of ulcer management. *C,* further reduction of crater size, after three months. *D,* lesion has completely disappeared.

abrupt transition from normally pliable and shapely walls to fixedly irregular narrowing of the lumen is characteristic. Small size of the lesion is not a reliable criterion of malignant tumor in the stomach, largely because gastric carcinoma is notoriously associated with little or no disturbance that is distinctive in the way of symptoms until the disease is in a well advanced stage.

Plate 65, *A*, represents an annular carcinoma which involves the portion of the stomach immediately proximal to the pyloric canal. It was not necessary for the lesion to attain great size to cause effective blockage of the gastric lumen. Pyloric obstruction, well shown by increased size of the stomach and by mottling of the barium column caused by retained food, brought this patient to examination because of persistent vomiting. Had the lesion developed at some point where it would not have caused obstruction, it is doubtful if the patient would have sought medical advice and assistance for many months, even years. Many such lesions are found at operation to be thoroughly amenable to surgical resection and thus are sometimes completely cured. Obstruction, because of the warning it provides for the patient, may well be considered a blessing in disguise.

A more advanced lesion which has gradually involved almost the entire lower half of the stomach is shown in Plate 65, *B*. Note that although the lumen is extensively deformed and narrowed, the central canal permits enough gastric content to pass to fill completely the extreme lower end of the stomach and the bulb of the duodenum. Distention of the uppermost part of the stomach indicates that the degree of obstruction was sufficient to cause vomiting. The tumor in this case has infiltrated the walls of the stomach over a considerable distance. Obviously, throughout the length of the lesion normal pliability and the ability to support peristaltic motility have long been lost. Sometimes gastric carcinoma burrows extensively in the stomach wall without developing masses of tumor tissue which protrude into the lumen. This expression of the disease has been called "linitis plastica."

The tumor shown in Plate 65, *C*, involves the middle section of the lesser curvature and has not completely encircled the stomach. The persistent, irregular filling defect is obvious and

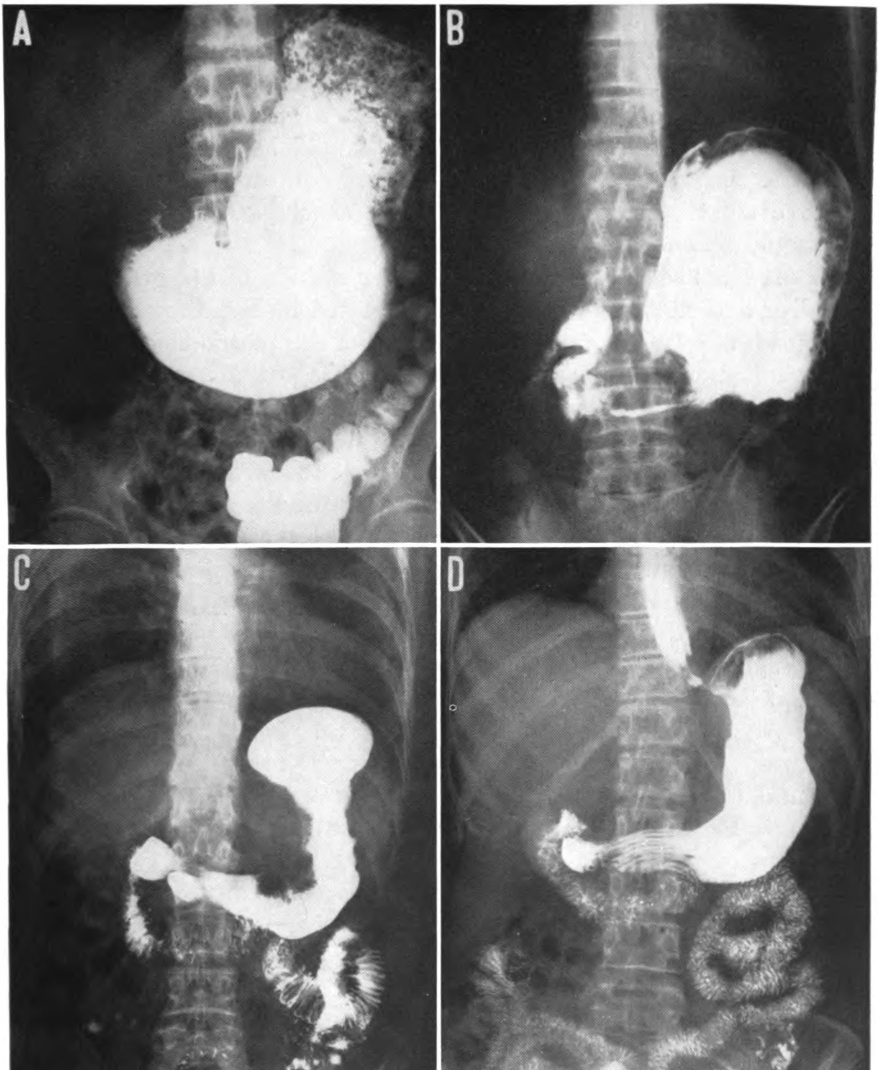


PLATE 65.—*A*, obstructing annular carcinoma, gastric outlet. *B*, advanced neoplasm almost obliterating lower half of gastric lumen. *C*, neoplasm deforming middle third of stomach. *D*, annular constricting neoplasm, gastric inlet and terminal portion of esophagus.

is to be considered entirely characteristic of gastric carcinoma. It is important for the would-be diagnostician to be alert in the recognition of filling defects, however small, because it is so desirable to recognize malignant disease in its early stages. Any persistent deformity of the stomach should be looked on with great suspicion. Frequently, re-examination may be necessary to evaluate the true status of the stomach, and this practice should be encouraged.

It has been mentioned that the recognition of benign peptic ulcer is difficult when the lesion is located high in the stomach. This is also true of gastric carcinoma. For this reason fluoroscopic examination of the region of the esophageal inlet should be carried out with the greatest care. In Plate 65, *D*, the classic characteristics of malignant tumor are clearly recognizable; the lesion has encircled the stomach at its cardiac orifice and has involved the extreme lower end of the esophagus as well. Patients with lesions in this location ordinarily complain of dysphagia and sometimes are thought to have simple benign cardiospasm. A point which should be borne in mind is that esophageal dilatation of the degree encountered in cardiospasm is seldom seen in patients who have a carcinomatous obstruction.

Altered anatomic relationships produced by operative procedures greatly complicate the radiologist's investigation of the status of the gastrointestinal tract. However, examinations after surgical operations that involve the stomach and intestine are highly important to the patient's welfare and might well be carried out far more frequently than is commonly the case. A record of the actual results of gastroenterostomy or other re-routing procedures made during convalescence may be of inestimable value if and when the patient develops digestive difficulties at some later date. A few of the more common surgical procedures of recalcitrant ulcers and malignant neoplasms of the stomach are illustrated to show how extensively the appearance of the upper gastrointestinal tract may be altered, as well as to show some of the complications which may be detected by x-ray means.

Because the third portion of the duodenum emerges from

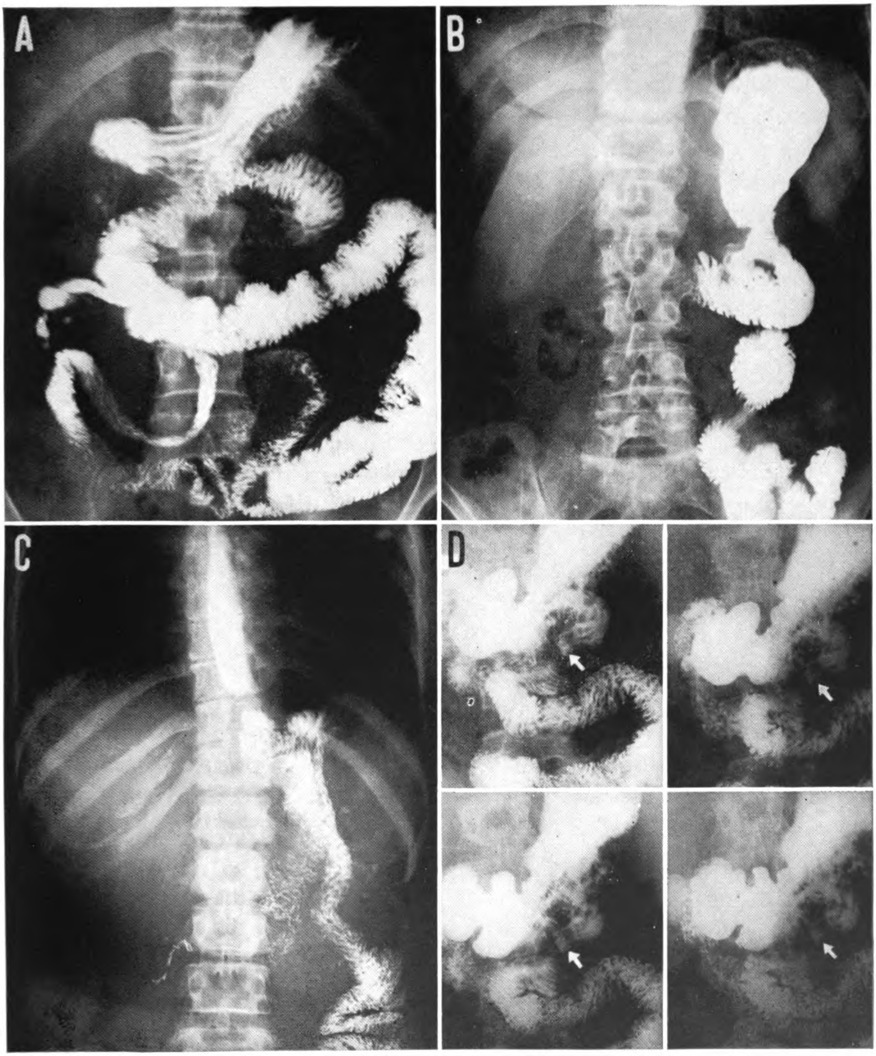


PLATE 66.—*A*, gastroenterostomy, posterior gastric wall near greater curvature. *B*, partial gastric resection. *C*, total gastrectomy. *D*, jejunal ulcer developing after gastroenterostomy.

behind to join the jejunum at a point near the greater curvature of the stomach, it is sometimes difficult to tell whether or not the jejunum has been anastomosed to the stomach and, if so, whether the stoma is patent or obstructed. It is important to observe how barium reaches the jejunum—by way of the pylorus or some surgical stoma. Plate 66, *A*, represents a normally functioning gastroenterostomy which is characteristic in all respects. The reverse looping of the small bowel, customarily employed to utilize peristalsis to the greatest advantage in the emptying of the stomach, is nicely shown. Stomachs to which the jejunum has been joined along the greater curvature usually show coarsening of the mucosal folds, and this feature can be recognized in this illustration.

In the patient whose film is reproduced in Plate 66, *B*, partial gastric resection has been performed to eradicate a stubborn duodenal ulcer. The blind segment of duodenum that leads to the point where the duodenum was resected can be identified where it extends horizontally toward the midline. The distal loop of jejunum extends directly downward. The outline of the spleen can be seen unusually well.

Surgical treatment of carcinomas located high in the stomach or spreading extensively from some lower point of origin consists in complete resection of the stomach and junction of the jejunum to the esophagus. The spectacular findings presented to the fluoroscopic observer after total resection are shown in Plate 66, *C*. Note the calcium deposits in the left lung and hilum, and in the spleen. These are entirely unrelated to the gastric lesion for which total resection was carried out. Note the metallic sutures in midabdomen which mark the site of resection at the lower end of the stomach. Both proximal and distal intestinal loops of gut are well shown.

Plate 66, *D*, consists of four serial exposures of a stomach positioned to show a postoperative jejunal ulcer which developed following gastroenterostomy. Note that the crater is located several centimeters downward from the stoma. This is not an uncommon location for recurrent ulcers.

Duodenal ulcer is the most common single diagnostic entity of clinical importance encountered in the course of x-ray gastro-

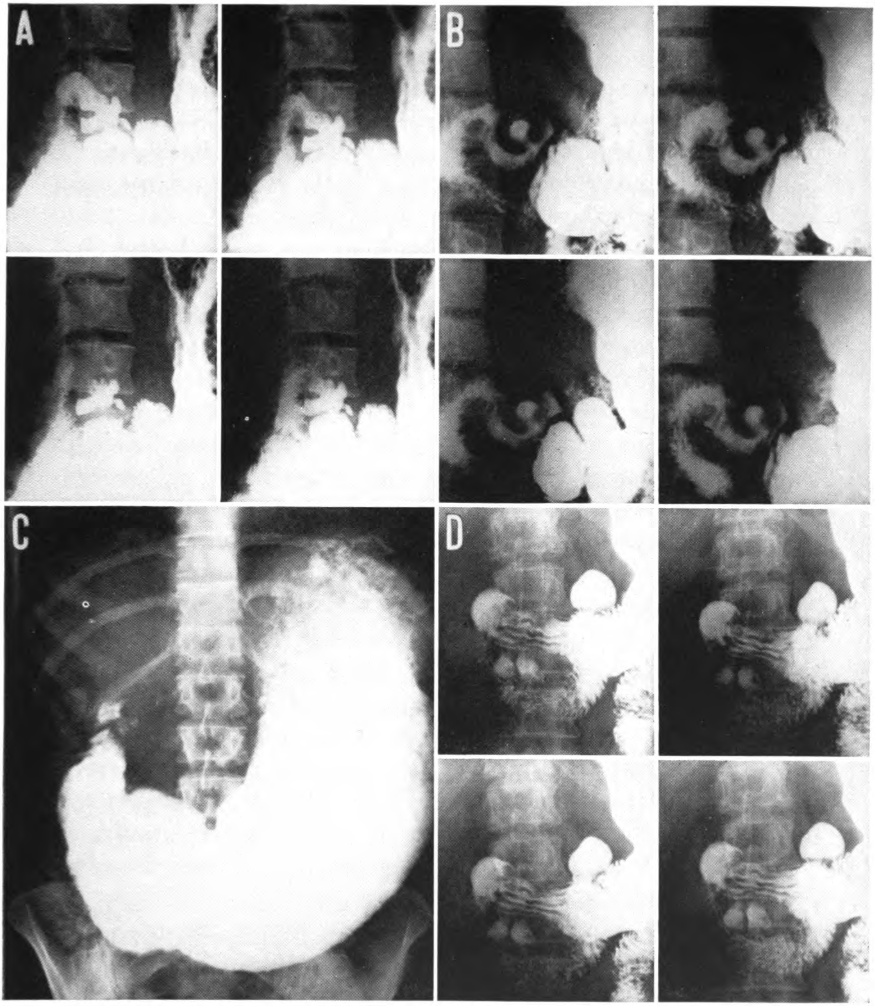


PLATE 67.—*A,* persistent deformity of duodenum; duodenal ulcer. *B,* another patient; ulcer crater visible on compression. *C,* chronic duodenal ulcer, gastric distention. *D,* multiple duodenal diverticula.

intestinal examinations. Common as it is,[2] this lesion is suspected on the basis of clinical symptoms far more frequently than its presence can be demonstrated either at the fluoroscope or in films. It may be that the threshold of recognition by x-ray methods is too high to permit every such ulcer to be identified, although frequently one is impressed by the fact that very small lesions can be demonstrated. Duodenal ulcers may occur at any point along the course of this part of the small bowel, but so frequently are they located in the first 1¼ in. segment or "bulb" that one sometimes fails to consider the likelihood of finding them at a lower level. It is the earnest aim of every radiologist to find and to demonstrate the actual defect in the duodenal mucosa whenever the diagnosis of duodenal ulcer is to be made, but sometimes it is necessary to be satisfied with secondary or associated signs of the lesion. Deep indentations along the contours of the duodenal bulb (Plate 67, *A*) presumably represent deformity due to spasm of bands of muscle within the gut wall induced by interference with the intrinsic nervous mechanism at the point of ulceration. Compression of the bulb to express most of the contained barium will sometimes show radiating folds of mucosa with a tiny residual fleck of opaque material at the point of convergence representing the break in the mucosal surface. In active ulcers, direct palpation over the crater will be associated with local tenderness. Careful observation of the duodenum in many projections is necessary if its true status is to be determined. Marginal deformity, an expression of scarring, may persist permanently after the ulcer itself has healed.

In Plate 67, *B*, the offending lesion is clearly recorded as a central fleck of barium surrounded by a clear areola which represents associated inflammatory infiltration of surrounding duodenal wall. Note that these illustrations, made in rather rapid sequence during the application of external pressure, show the fleck equally well in all four exposures. Without the use of pressure this lesion would have escaped notice. The ulcer in this case is a large one.

---

(2) At the University Hospital each year approximately 450 persons are found to have x-ray signs of duodenal ulcer.

High-grade obstruction of the gut lumen at the gastric outlet is not an infrequent complication of duodenal ulcer (Plate 67, *C*). This can occur during the active inflammatory stage or as the aftermath of such activity if healing has resulted in the formation of excessive scar tissue. The study of patients suspected of harboring duodenal ulcer or its after-effects represents an important and difficult phase of the work of a radiologist engaged in gastrointestinal diagnosis.

Diverticula of the small intestine are not at all uncommon in patients who have no symptoms of digestive disturbance. When they are encountered in persons suspected of some alimentary abnormality, the urge is great to ascribe dire significance to them. Duodenal diverticula are most common at a point close to the ampulla of Vater on the medial aspect of the duodenal loop. Plate 67, *D*, shows two pouches at this location, and a third and larger pouch extends upward from the third portion of the duodenum.

In recent years more and more attention has been directed to the status of the small intestine by observers in the field of roentgenology. Organic lesions of the jejunum and ileum are not common, and functional disturbances are extremely difficult to identify and to understand. Certainly much can be learned about the variations from the expected normal which can be used advantageously in gastrointestinal diagnosis. Ambiguous and poorly substantiated comments which suggest some vague dysfunction have little practical value and may be more misleading than helpful. Examination of the entire course of the small intestine with anything like the completeness which is mandatory for the esophagus, stomach and duodenum is most difficult because of the time required for the administered opaque meal to traverse its many feet of length. Only within general limits can one be sure of exact locale when variations from the normal are found in segments of the small bowel. Lesions which materially obstruct the passage of food or which profoundly affect the rate of small bowel motility can be postulated when the rate of food transit is found to be greatly altered on examination five or six hours after administration of the opaque meal.

In Plate 68, *A*, a film of the entire abdomen shows both the barium-filled stomach and the outlines of a considerable portion of the small intestine. Note the delicate feathery appearance of the barium which has accumulated between the valvulae conniventes in the jejunum. This pattern is characteristic of partially filled jejunum. At a lower level, where the small bowel pattern appears quite different, the loop which swings to the right of the spine is more completely filled and the pattern imparted to the gut margins is much coarser. This represents ileum. If it were always possible to control barium filling, as in this instance, the study of small intestinal function and structure would be much simpler. Unfortunately, this is not the case.

When the lumen of the small intestine is obstructed or when intrinsic nervous mechanism is so disturbed that it prevents normal muscular tone and peristalsis, the small bowel is capable of enormous distention. The ballooning of a large section of the small intestine shown in Plate 68, *B*, is the result of extensive hemorrhagic infarction of small bowel which was the terminal episode in fatal pulmonary tuberculosis. Note how greatly the lumen has been enlarged and how extensively the mucosal folds have been separated and flattened. Note also the sausage-like shape of the various loops which are closely packed together. This appearance, when seen, spells intestinal obstruction, and the patient may be subjected to the type of x-ray examination required to show such findings, regardless of the severity of his illness, since no feeding or other preparation is necessary.

Plate 68, *C*, is presented as a typical example of the distribution of barium to be expected five hours after feeding. Although in the passage of intestinal contents through the alimentary tract the timetable of events is not strictly and exactly reliable, in normal individuals it is customary to find that, at five hours, administered barium will have progressed for some distance into the large intestine while emptying of the lower small bowel will not be complete. In general, the ingested barium, will be found, for the most part, to the right of the midline and below the umbilicus.

The situation recorded in *D* certainly does not conform to the ordinary schedule of events at five hours. Several things

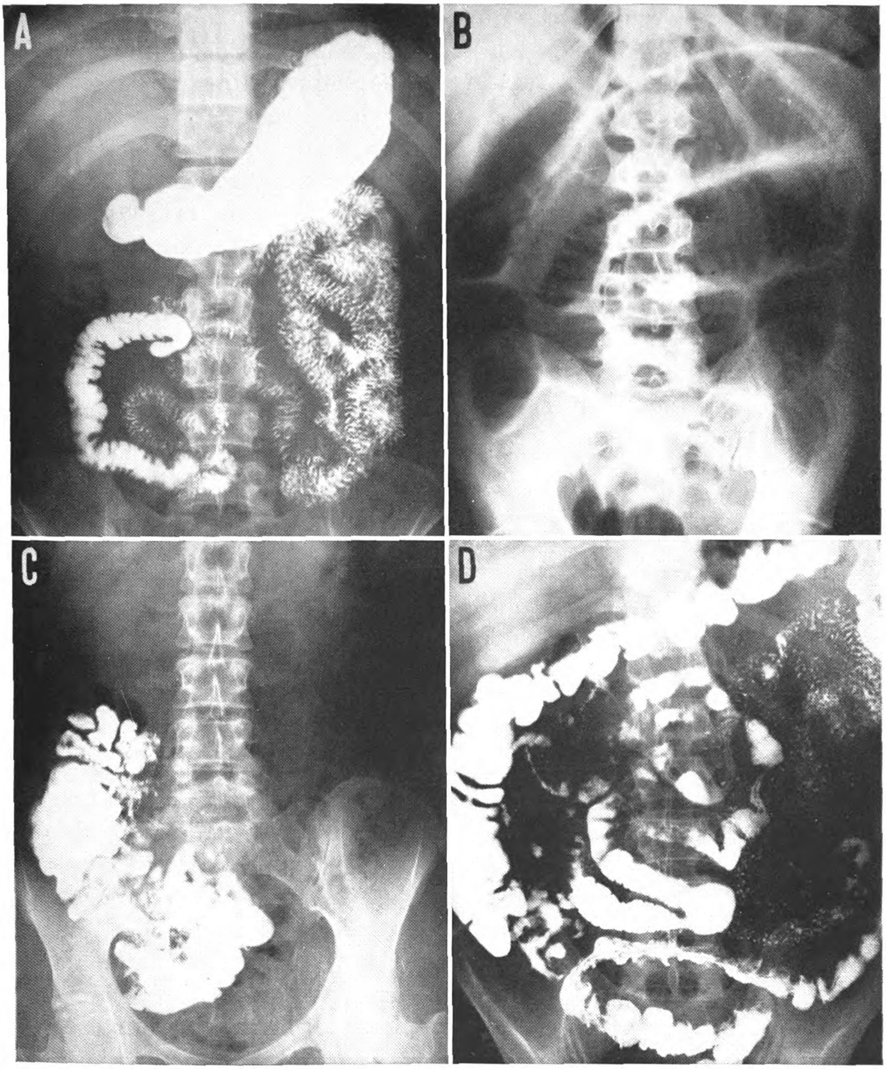


PLATE 68.—*A,* barium-filled stomach and upper small intestine; normal. *B,* gas distention of denervated small intestine. *C,* typical distribution of barium, five hours after feeding. *D,* abnormal five hour distribution; "small bowel dysfunction."

seem to be wrong. Barium has been propelled unusually rapidly to fill the entire colon, while much of the small intestine still contains opaque material. In addition, the customary mucosal pattern is lacking, and the lumen of the small intestine is at some points much narrower than normal, at others broader. With our present knowledge we can only report "Small bowel dysfunction," which will indicate that, in some manner, the complicated nervous apparatus, both intrinsic and extrinsic, which usually operates to maintain orderly advancement of the bowel contents and caliber of the lumen has failed to perform as expected: It is not uncommon for patients with uncontrolled diabetes, pernicious anemia or any other condition associated with peripheral neuropathy to exhibit similar derangements of small bowel function.

THE BILIARY TRACT

X-ray methods of examination have won a place of enviable importance and reliability in the detection of disease of the biliary system. Cholecystography—the x-ray examination of the gallbladder following the administration of opaque substances which are largely excreted in bile—has been primarily responsible for the clinical successes credited to radiologic examination of the biliary apparatus since Graham and his associates devised and introduced the method. Following its secretion, bile is accumulated in the gallbladder, which structure has the ability to concentrate this fluid to a high degree. When the patient is properly prepared, the normal gallbladder can be recognized without difficulty by the dense shadow cast by the concentrated opaque material. The results of cholecystographic examination can be expressed in simple and significant terms as follows (Plate 69, *A–F*): *A*, normal visualization without stone; *B*, faint visualization without stone; *C*, nonvisualization without stone; *D*, normal visualization with stone; *E*, faint visualization with stone; *F*, nonvisualization with stone.

Normal visualization indicates, of course, that the gallbladder's ability to concentrate bile has not been impaired and, further, that bile is able to reach the viscus. Faint visualization

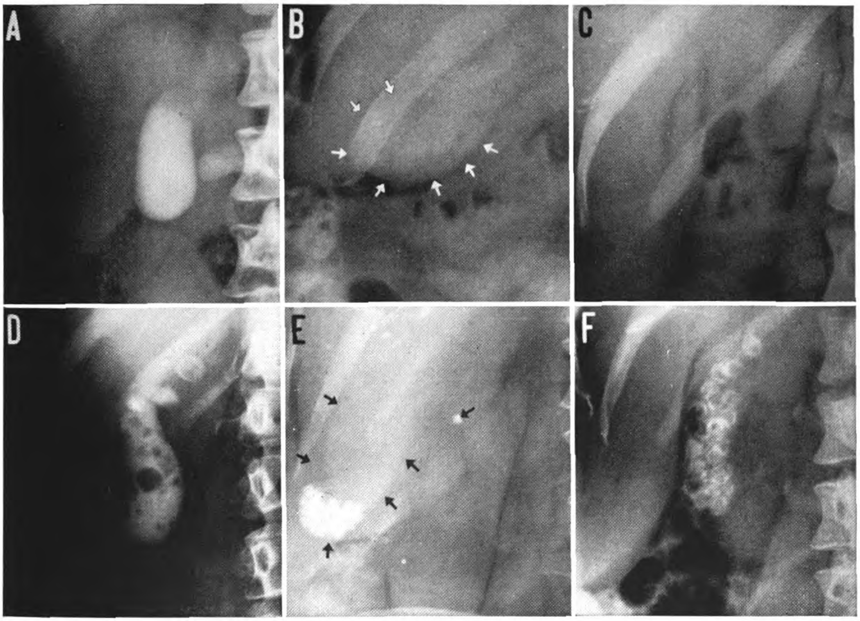


PLATE 69, A–F.—Normal and abnormal cholecystograms. *A*, normal visualization without stone. *B*, faint visualization without stone. *C*, nonvisualization without stone. *D*, normal visualization with stone. E, faint visualization with stone. *F*, nonvisualization with stone.

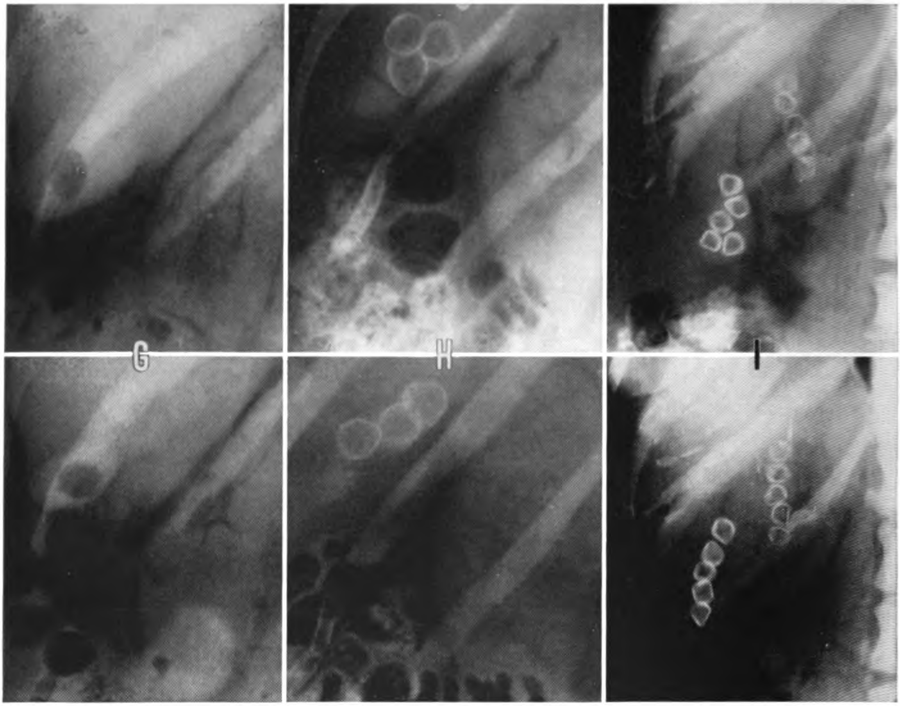


PLATE 69, G–I.—Abnormal cholecystographic findings. *G,* normal visualization with solitary transparent stone; *below,* note shrinkage of gallbladder shadow after fat feeding. *H,* faint visualization with three partially opaque stones; *below,* note rearrangement of stones with gallbladder shrinkage following fat feeding. *I,* nonvisualization with clustered semiopaque stones in gallbladder and columnated stones in common duct; *below,* both groups are arranged in line as gallbladder contracts after fat feeding.

indicates that concentrating power has been impaired. Nonvisualization, barring technical errors in preparation or filming, means that gallbladder function has been lost or that no bile has reached its lumen, or that the liver has not secreted bile in normal amounts.

Stones within the gallbladder or duct system can be demonstrated by x-ray means if they contain sufficient radiopaque salts to cast a shadow. If, following cholecystographic preparation, sufficient concentrating power permits the accumulation of opaque material in the gallbladder lumen, even totally nonopaque stones are visible in relief. Thirty-three per cent of all stones can be found without gallbladder visualization. The percentage rises to over 95 when concentrating power is maintained.

Plates 69, *A–F* and *G–I,* show the various results of cholecystography. Note in particular the single stone which lies some distance from the main cluster in *E.* In all probability this has been expelled into the cystic duct, which accounts, perhaps, for the faintness of the gallbladder shadow. Views *G, H* and *I* show the advantages sometimes obtained when initial filming is followed by the feeding of fat and refilming within the hour. Fat-feeding produces shrinkage of the gallbladder, which, in turn, causes rearrangement of contained stones. The pool of opaque bile at the tip of the fundus in *H* is partially segregated from the main cavity of the gallbladder by a congenital constriction. This condition is not uncommon and is of no clinical importance. In this instance the stones are too large to pass beyond the constriction and into the fundus. In *I* clustered semiopaque stones within the gallbladder are associated with similar stones arranged in vertical alignment within the common duct. Note that following fat-feeding the gallbladder has contracted to tubular form and both groups of stones are arranged in single file.

Somewhat more spectacular x-ray methods of studying the biliary apparatus in search of clinically valuable information are illustrated in Plate 70. In *A* is shown opaque injection of a rubber T-tube that was left in the common duct at the time of cholecystectomy. After operation and before withdrawal of the soft tube the status of the biliary radicles within the liver and of the common duct to its terminus in the duodenum has

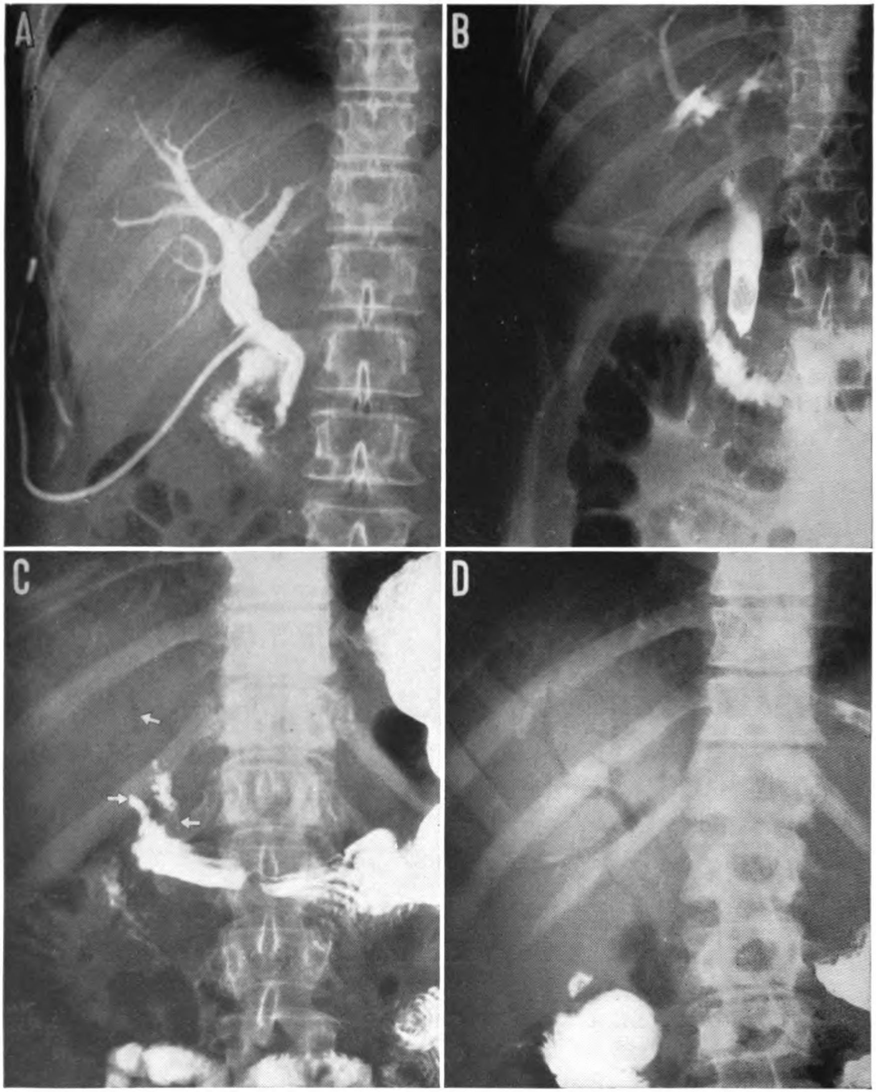


PLATE 70.—*A,* normal choledochogram. *B,* choledochogram, solitary nonopaque stone in dilated common duct. *C,* barium and gas in biliary ducts. *D,* gas inflation of biliary ducts.

been demonstrated by the injection of highly concentrated diodrast®. The entire biliary tract appears to be normal. In the case presented in *B,* trouble has been found. The clear area surrounded by the contrast material at the lower end of the common duct is produced by a solitary stone which must be removed before the patient will be cured.

Plate 70, *C,* shows the escape into the biliary ducts of some of the barium administered by mouth. This fortuitous observation proved the existence of a fistulous communication between the alimentary tract and the biliary system.

A most spectacular and valuable diagnostic sign of biliary tract disease is shown in *D.* Routine films of the abdomen prepared following the administration of barium by mouth show the liver radicles and the major ducts, as well as the gallbladder, to be outlined with air that could only have reached them from the alimentary tract. Spontaneous cholecystoduodenostomy has occurred in this patient, probably associated with the expulsion of stones into the gut.

Many improved opaque materials for cholecystography and cholangiography have appeared since 1948. The latest of these, which must be introduced by vein, is capable of opacifying the biliary duct system in many patients within 45 minutes to an hour even after the gallbladder has been removed surgically. This procedure has opened the door to preoperative identification of common duct stone, at least in some patients.

THE LARGE INTESTINE

X-ray examination of the large intestine is best accomplished after injection of barium sulfate in watery suspension per rectum. Thorough cleansing of the gut lumen to remove all traces of fecal material is an essential preliminary step. Injection should be carried out slowly to permit the fluoroscopist to inspect the tortuous tube in great detail before complete filling. After filling, many of the convolutions are hidden, particularly in the pelvic portion, where lesions are most commonly found. It is necessary to rotate the patient from side to side during examination, and any procedure is inadequate which depends solely on

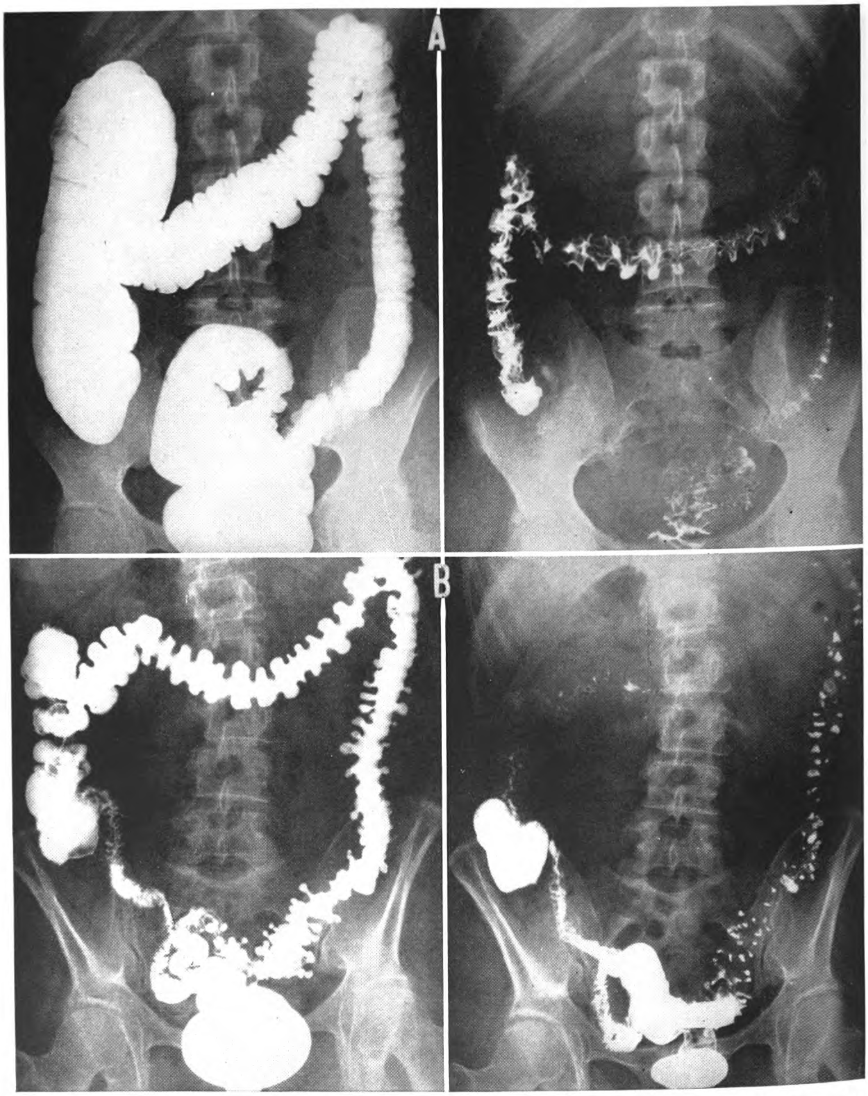


PLATE 71.—*A*, barium-filled colon before and after evacuation; normal. *B*, similar exposures, showing multiple diverticula in descending and sigmoid segments.

roentgenograms prepared after injection. Depending on findings observed at the screen, various exposures are planned and carried out. It is good standard procedure to prepare a minimum of two films, one to show the appearance of the colon when completely filled, another to record the appearance after voluntary defecation. Plate 71, *A*, represents the pre- and postevacuation films of a patient in whom no abnormality was discovered on colon examination. These standard exposures are complementary: each shows findings not apparent in the other. Uninformed observers are apt to find alarming signs of colonic disease in every postevacuation exposure, calling attention to the narrowing of the lumen and the crinkled folds of the mucosa. These appearances are exactly what one should expect to find in a colon which has just performed the function of emptying out its contents. The postevacuation film often shows parts of the colon which were hidden by overlying parts in the initial exposure; and, furthermore, it gives the observer an opportunity to see the mucosal surface.

The advantage of using these two recorded observations is well demonstrated in Plate 71, *B*, for the numerous pseudodiverticula distributed along the course of the descending colon are much more clearly visible as accessory pouches when the main lumen of the gut has been emptied. The ability of the gut walls to stretch when the colon is full, as well as to contract when the lumen is empty, is worth knowing, because in many abnormal situations this ability is impaired or lost.

Other schemes can be used to good advantage to gather more complete information about various segments of the colon. The commoner ones are shown in Plate 72. The appearance of a colon immediately after the introduction of barium is shown in *A*. Obviously, the patient was not well prepared for the examination because large irregular defects in the barium column represent retained fecal masses. There is an accumulation of gas in the cecum. There seems to be some abnormal irregularity in the contour of the sigmoid in the midline of the pelvis. Partial explanation for the retention of feces in the colon is found in the postevacuation film (*B*), for, although barium has been expelled from the rectum, there has been little drainage

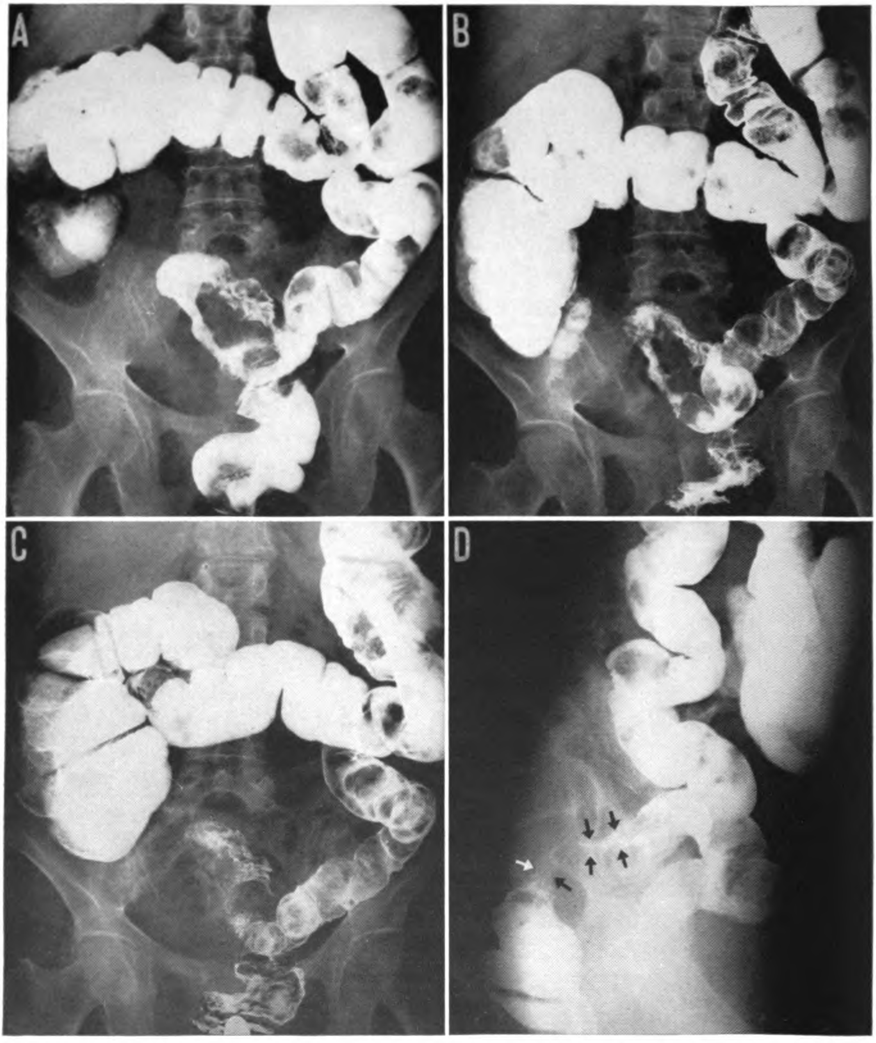


PLATE 72.—Carcinoma of sigmoid colon. *A*, pre-evacuation film. *B*, postevacuation film. *C*, double-contrast film. *D*, in this case lateral projection shows the lesion to best advantage.

of the major portion of the gut. One strongly suspects partial obstruction in the midsigmoid. Double-contrast preparation (*C*), accomplished by filming after the injection of air, has added little information in this case, although this device often is most helpful, as will be seen in subsequent illustrations. Finally, by a direct lateral projection (*D*), the entire course of the rectosigmoid colon can be followed without the confusion caused by the superimposition of several bowel loops, and in this film the annular constriction produced by a sigmoid carcinoma is brought into view. By basing roentgenographic procedures on fluoroscopic observations, the roentgenologist can make use of many ingenious devices to record his observations.

Carcinoma of the colon should always be suspected in patients over 40 who complain of digestive tract symptoms, however vague. Mention of the age 40 does not imply that malignant tumors never occur earlier, but rather it calls attention to the far greater incidence beyond that age. Lesions of this type may be recognized in a variety of ways, but always, if x-ray signs are carefully scrutinized, by the presence of a fixed filling defect abruptly demarcated from neighboring normal gut and almost always limited to a relatively short segment of the colon. More than half the malignant neoplasms of the large intestine occur in the portion of the descending colon that lies below the iliac crest—the sigmoid and the rectum. It is not uncommon to encounter complete obstruction to the column of barium injected from below even though the patient is able to pass stools without symptoms of obstruction. Masses of tumor tissue extending into the colonic lumen may act as valve leaflets which block the lumen when the direction of the stream is reversed.

A characteristically short and completely annular neoplasm in the transverse colon to the right of the spine is clearly shown in the initial pre-evacuation film reproduced in Plate 73, *A*. Note that the slight pressure of injection has distended the lumen more completely below the lesion than on the proximal side. This is logical, of course, since the point of narrowing restricts the rate at which barium can pass beyond the lesion.

Air injection following the postevacuation film has been used to produce the appearance of the lesion in the descending colon

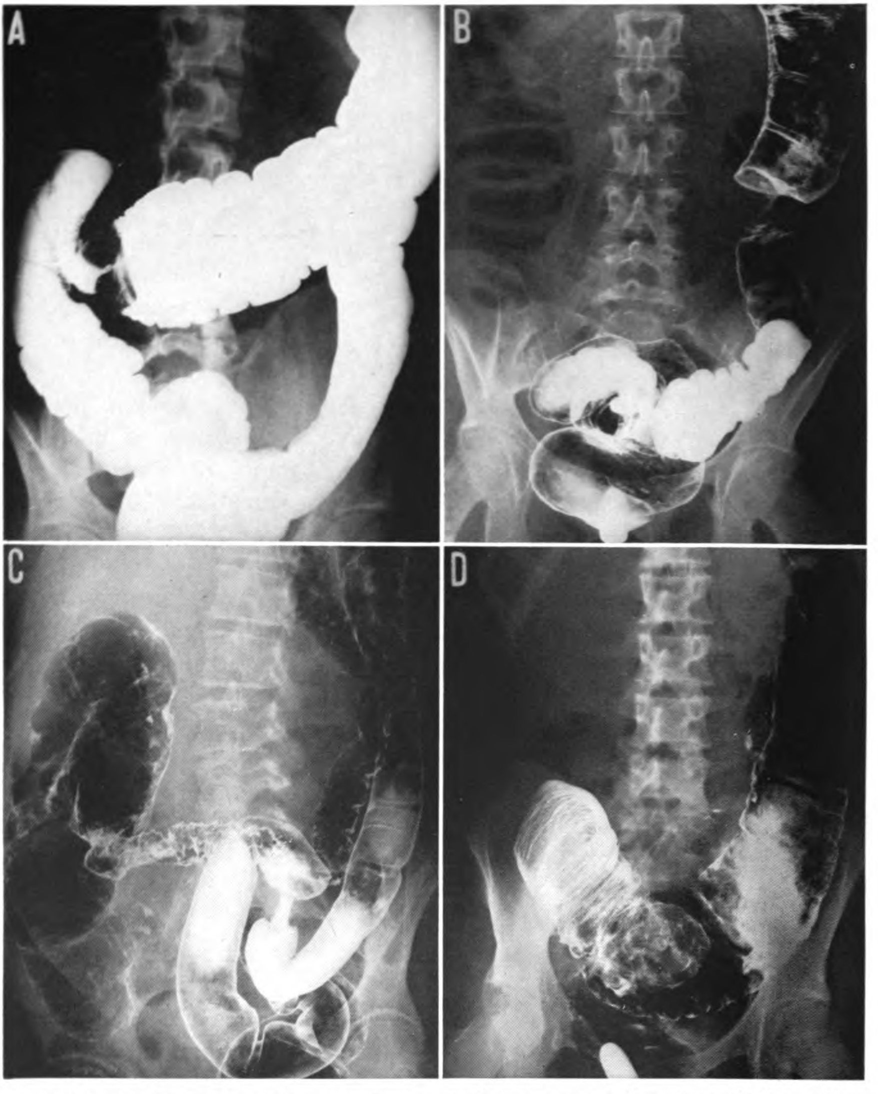


PLATE 73.—Colonic carcinomas. *A,* proximal transverse colon. *B,* mid-descending colon, double-contrast. *C,* sigmoid colon, oblique view. *D,* intussusception; see shadow of tumor in air-filled colon at midpelvis.

in Plate 73, *B.* Double-contrast films may be prepared stereoscopically to provide an opportunity to see the inflated gut in three dimensions and to study the surfaces of the lumen. When thus viewed, the lesion shown here is even more obvious and characteristic in appearance. In Plate 73, *C,* oblique projection of the colon has been used to demonstrate an annular carcinoma of the sigmoid to the best possible advantage.

Intussusception of the ileocecal portion of the alimentary tube into the transverse colon does not often occur; but when it does, the x-ray appearance is striking. The instigating cause of such telescoping of gut is almost always an intraluminal tumor which is propelled by peristaltic action with such force that a portion of the intestinal wall is carried along with the tumor into the lumen of the gut distally. In Plate 73, *D,* the typical appearance, resembling a coil spring, is to be seen; the outline of the tumor itself is silhouetted against the air which was injected after the evacuation of the bulk of the barium enema. The ringlike shadows proximal to the mass are produced by barium trapped in the deep crevices between folds of the colonic mucosa throughout the zone of intussusception.

"Colitis," as used by the radiologist, implies very real and easily demonstrable organic abnormality of the colon in contradistinction to the nondescript symptom complexes which often are so designated by patients and their physicians. Many classifications of inflammatory disease of the colon have been presented in the literature, and some differences in x-ray signs seem to justify their recognition. In general, however, the radiologist does well to identify a few well-defined types of inflammatory disease according to the particular findings he observes.

Thromboulcerative colitis habitually begins in the rectum and spreads proximally, often until it involves the entire large intestine. In the early stages, this disease is characterized radiologically by shaggy ulcer pockets along the margins of the lumen; these extend out into the deep layers of the wall, to be limited by the serous surface (Plate 74, *A*). The volume of the rectum is reduced. The ulcers are best seen in the transverse portion

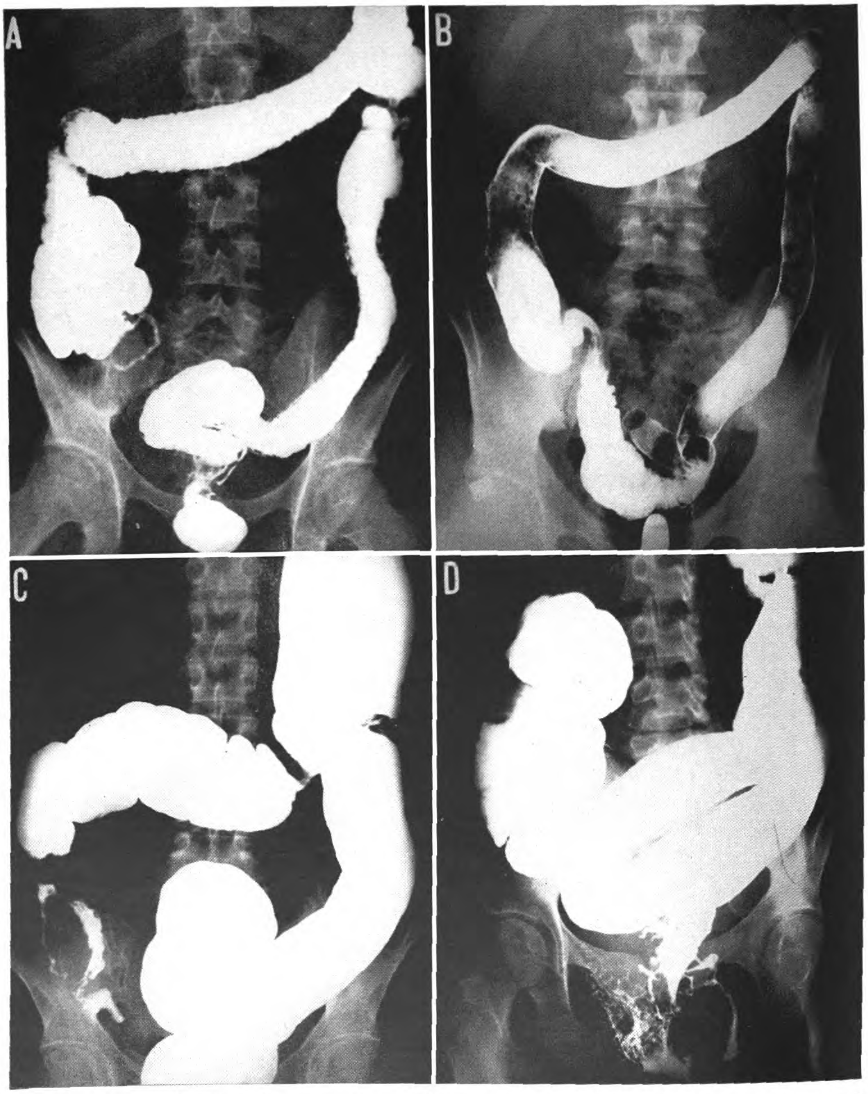


PLATE 74.—*A,* thromboulcerative colitis; ulcer craters visible in transverse and descending segments. *B,* decreased caliber and length of colon; late stage of chronic ulcerative colitis. *C,* deformity of cecum and ileocecal junction; tuberculous colitis. *D,* rectal and perirectal lesions of lymphogranuloma venereum.

of the colon and in the lower left quadrant. It is noteworthy that inflammatory disease of the colon obliterates the normal haustral pattern which is characteristic of the normal bowel.

As the disease progresses or as it undergoes attempted healing, the deep ulcers are no longer visible. The colonic tube, largely denuded of its mucosal lining, becomes progressively contracted in length and breadth. When it is observed in air-filled segments, the inner surface appears pebbled. All of these features are found in Plate 74, *B*.

Inflammatory lesions which begin in the right colon or are largely confined to that part of the bowel often prove to be of tuberculous or amebic etiology. A nonspecific lesion, usually described as Crohn's ileocolitis, may have its starting point near the ileocecal junction, and characteristically it progresses distalward in the colon and proximalward in the small bowel. A typical example of tuberculous ileocolitis is given in Plate 74, *C*. Note that the blind end of the cecum has shrunk to a mere thread and that the terminal portion of the ileum has lost its normal width of lumen and its typical mucosal pattern. A second point of involvement is to be seen in the transverse colon, almost concealed by overlapping descending colon. Note that, unlike thromboulcerative colitis, the rectal pouch is of usual dimensions.

A less common but spectacular and clinically serious form of inflammatory disease of the rectum and perirectal tissues is seen in the film of a Negro woman reproduced in Plate 74, *D*. The divergent fingers of barium which extend in various directions from the rectum are fistulous tracts in a patient with lymphogranuloma venereum.

Hirschsprung's disease, characterized by great distention of the colon with incomplete evacuation on defecation, has been recognized in recent years as an expression of congenitally defective intrinsic innervation of a rectal segment of variable length. Persistent narrowing of the defective segment with distention proximal to the site of defect is demonstrated easily by radiologic methods in most instances, and fortunately this disease can be successfully treated by surgical means.

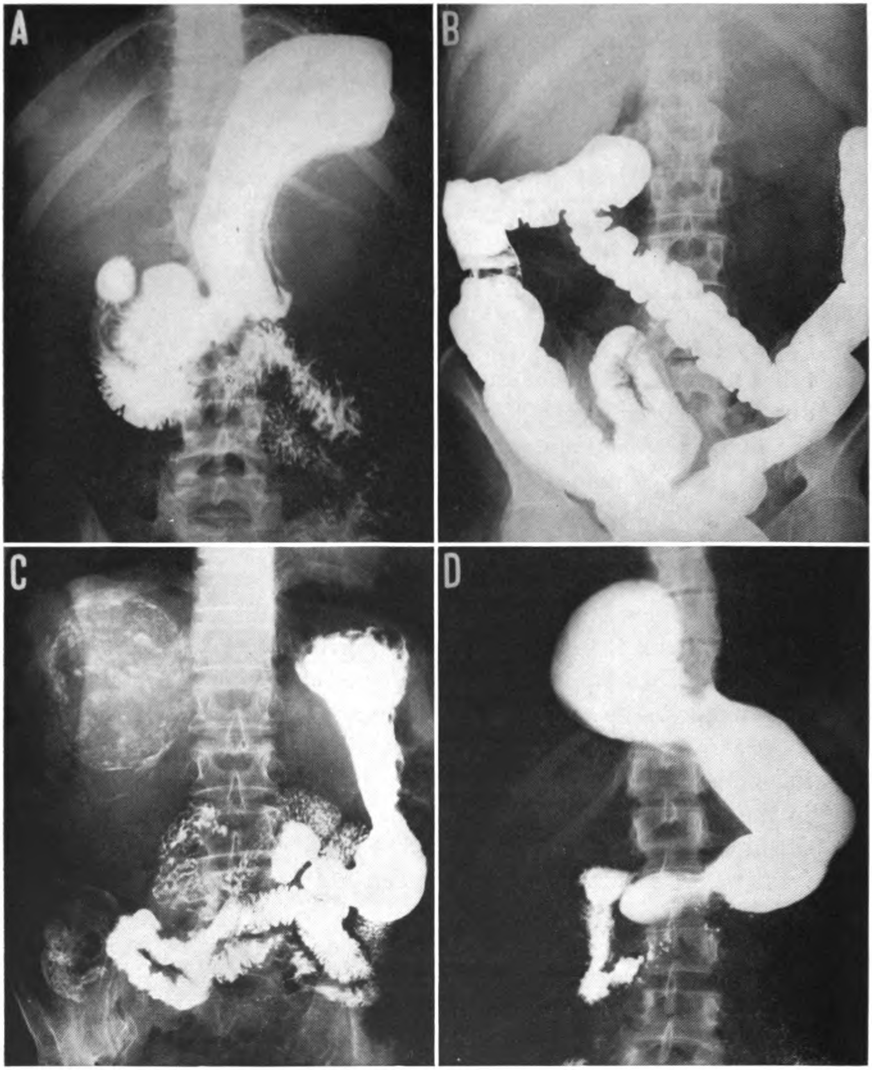


PLATE 75.—Extra-alimentary abdominal abnormalities. *A*, cyst of tail of pancreas, deforming stomach. *B*, displacement and deformity of colon by liver enlargement. *C*, partially calcified echinococcus cyst in right lobe of liver. *D*, enlarged esophageal hiatus of diaphragm, partial herniation of stomach.

THE ABDOMEN GENERALLY

Numerous abnormal conditions of the abdomen which may be encountered during gastrointestinal examinations but which do not represent intrinsic lesions of the digestive tract proper are, in the aggregate, of great importance in medical practice. It is well to bear in mind that a survey film of the abdomen may uncover otherwise entirely unsuspected evidences of disorder. The distortion of the stomach contour seen in Plate 75, *A*, does not represent intrinsic gastric disease but does call attention to the presence of a large cyst in the tail of the pancreas which has displaced the stomach and indented its contour. Somewhat similar crowding of the hepatic flexure of the colon is shown in *B*, the result of downward displacement due to enlargement of the liver.

The circular patch of flakelike calcium deposits visible beneath the right leaf of the diaphragm in Plate 75, *C*, identifies an echinococcus cyst of the liver. Many other types of calcium deposition within the abdomen, such as calcified fibromyomas of the uterus, calcified mesenteric lymph nodes, fetal skeletons, etc., when present, can be detected and often identified.

As one last example of the sort of extra-alimentary abnormality that can be discovered easily by x-ray examination, Plate 75, *D*, shows herniation of the cardiac portion of the stomach into the thoracic cavity by way of an enlarged esophageal hiatus. Many such hernias will escape notice unless the patient is examined in the horizontal position. In addition to herniation of the stomach, one sometimes sees large segments of small intestine and colon migrating into the thorax. Sometimes the hernial sac contains omentum only, and then one must depend on telltale displacement of the transverse colon as the result of traction to make the diagnosis. Hernias of all types and in all locations may be demonstrated by x-ray methods. The single example illustrated will serve as a reminder that such lesions can be found if intelligent search is made. Enlargement of the urinary bladder, uterus, kidney, spleen or abdominal lymph nodes, as well as abscesses, hematomas or tumors, may displace or distort digestive organs.

READING LIST

ASTLEY, R.: *Radiology of the Alimentary Tract in Infancy* (Baltimore: Williams & Wilkens Company, 1956).

CARMAN, R. D.: *The Roentgen Diagnosis of Diseases of the Alimentary Canal* (Philadelphia: W. B. Saunders Company, 1917, 1920).

CASE, J. T.: Fifty years of roentgen rays in gastroenterology, Am. J. Roentgenol. 54:607–625, December, 1945.

COLLER, F. A.; KAY, E. B., AND MACINTYRE, R. S.: Regional lymphatic metastases of carcinoma of colon, Ann. Surg. 114:56–67, July, 1941.

FRIMANN-DAHL, J.: *Roentgen Examinations in Acute Abdominal Diseases* (Springfield, Ill.: Charles C Thomas, Publisher, 1951).

GOLDEN, R.: *Radiologic Examination of the Small Intestine* (Philadelphia: J. B. Lippincott Company, 1945).

GRAHAM, E. A., AND COLE, W. H.: Roentgenologic examination of the gallbladder: New method utilizing the intravenous injection of tetrabromphenolphthalein, J.A.M.A. 82:613–614, 1924.

HARRINGTON, S. W.: Diaphragmatic hernia: Results of surgical treatment in 210 cases, California & West. Med. 51:27, July, 1939.

HODGES, F. J.: *The Gastro-intestinal Tract: A Handbook of Roentgen Diagnosis* (Chicago: Year Book Publishers, Inc., 1944).

——, AND LAMPE, I.: Comparison of oral cholecystographic findings and proved evidences of gallbladder disease, Am. J. Roentgenol. 37:145–153, February, 1937.

KIRKLIN, B. R.: Background and beginning of cholecystography, Am. J. Roentgenol. 54:637–639, December, 1945.

LODGE, T.: *Recent Advances in Radiology* (3d ed.; Boston: Little, Brown & Company, 1955).

MILLER, T. G., AND ABBOTT, W. O.: Intestinal intubation: Practical technique, Am. J. M. Sc. 187:595–599, May, 1934.

SCHATZKI, R.: Comparative value of gastroscopy and roentgen examination of the stomach, Radiology 29:488–491, October, 1937.

——, AND HAWES, L. E.: Roentgenologic appearance of extramucosal tumors of the esophagus, Am. J. Roentgenol. 48:1–15, July, 1942.

SHANKS, S. C., AND KERLEY, P. (ed.): *A Textbook of X-ray Diagnosis* (2d ed.; Philadelphia: W. B. Saunders Company, 1951), vol. III.

STEVENSON, C. A.: The development of the colon examination, Am. J. Roentgenol. 71:385–397, March, 1954.

SUSSMAN, M. L., AND WACHTEL, E.: Granulomatous jejuno-ileitis, Radiology 39:48–53, July, 1942.

SWENSON, O.; NEUHAUSER, E. B. D., AND PICKETT, L. K.: New concepts of etiology, diagnosis and treatment of Hirschsprung's disease, Pediatrics 4:201, 1949.

TEMPLETON, F. E.: *X-ray Examination of the Stomach* (Chicago: University of Chicago Press, 1944).

YOUNG, B. R.: Roentgen examination of the acute abdomen, Radiology 64:483–497, April, 1955.

8

The Genitourinary Tract

FOR 20-ODD YEARS after their discovery, x-rays seemed destined to play a limited role in the field of urologic diagnosis. Soon after the earliest beginnings of diagnostic radiology, technics were developed which made it possible to record on ordinary glass photographic plates all the minute structural details of the bones in the thinner portions of the extremities. Neither x-ray apparatus nor photographic materials were sufficiently perfected to permit brilliant results to be achieved in examinations directed toward the thicker portions of the adult human body. Secondary radiation, produced in great quantity as the exploring beam of x-rays was in part absorbed by layers of soft tissue, blackened photographic emulsions without imparting the desired shadows of anatomic parts. It seemed to many physicians that x-ray methods of examination would never be of spectacular assistance in diagnosis related to deeply situated organs, except in the search for metallic foreign bodies.

This state of affairs was abruptly altered when, in 1917, Dr. Hollis Potter of Chicago reported his newly devised apparatus that filtered out most of the secondary radiation before it could reach the recording photographic surface. By using this instrument, the Potter-Bucky diaphragm (Plate 6, p. 38), radiologists for the first time were able to produce clearly defined images of deep-seated anatomic structures. In short order, the urinary tract was subjected to exhaustive radiographic ex-

ploration, and today urologic roentgenography is an exceptionally well-tilled and fertile field. The perfection of various technics that involve the use of contrast materials has enormously improved the accuracy of urologic diagnosis.

X-ray contributions to the clinical study of male and female genital organs, although far less widely applicable, have proved to be of considerable practical value. In particular, otherwise unobtainable information concerning the fetus in utero can be gleaned from roentgenograms of the mother throughout the second and third trimesters of pregnancy.

The following technical procedures are the ones commonly used in dealing with lesions of the genitourinary tract.

Survey film.—Ordinarily this consists of a single anteroposterior exposure made on large film with the patient in the recumbent position. The resulting roentgenogram is familiarly known as a KUB film because it is intended to cover the entire area occupied by the kidneys, the ureters and the urinary bladder. On this roentgenogram the important landmarks are the renal shadows, the tall, triangular paraspinal shadows of the psoas muscles, the lumbosacral vertebrae and the pelvic bones. If the urinary bladder is distended by urine, it too may be visible. Somewhat similar exposures of the abdomen and pelvis in both anteroposterior and lateral projections are used in the examination of the female genital organs and the birth canal, especially during pregnancy.

Retrograde pyelography.—After the insertion of long, slender, radiopaque catheters via the cystoscope, their positions are recorded on a survey film similar to the KUB exposure. The renal pelves and calices are then filled with opaque medium injected through the catheters, and the second exposure of the standard pyelographic series is made to show these structures. During withdrawal of the catheters additional opaque material is injected to fill the ureters and, with the least possible delay, a third film is exposed in which the ureters and sometimes the partially filled bladder can be seen (Plate 76). Many examiners complete the series with a final film exposed with the patient semi-upright to show the degree of renal mobility and to delineate the lower ureters to better advantage.

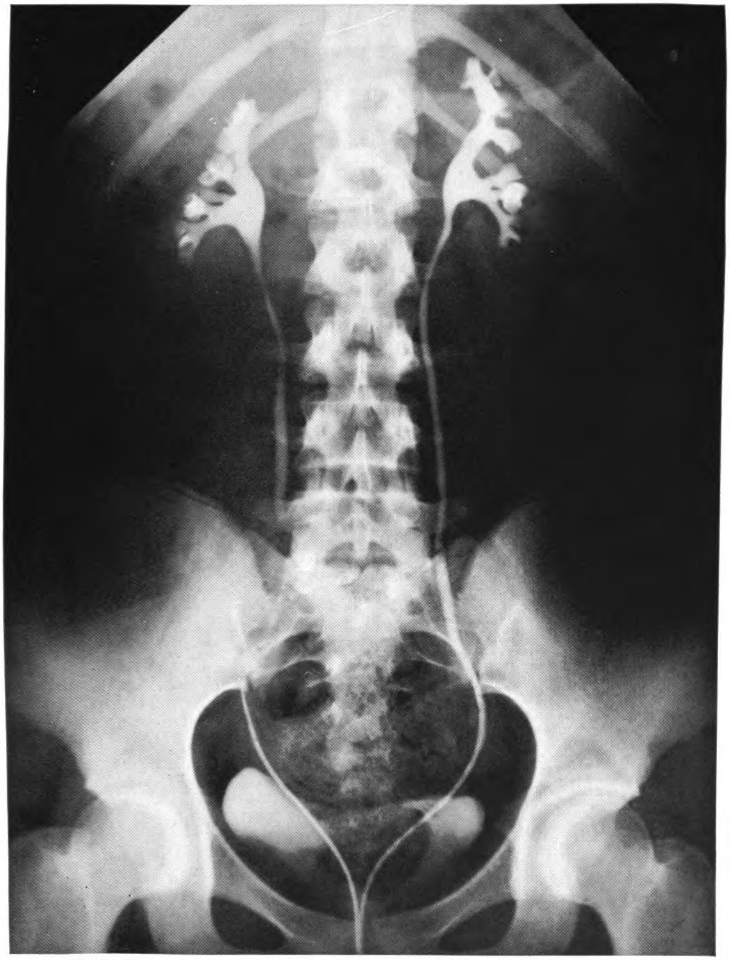


PLATE 76.—Normal retrograde pyelogram.

Excretory pyelography.—In this procedure the opaque medium is injected intravenously and is subsequently excreted by the kidneys into the calices, pelves, ureters and bladder. A preliminary film is exposed before the injection of the contrast material; and, following the injection, additional exposures are made at intervals varying from five minutes to as long as two hours, depending on the rapidity of excretion. Again an upright film may prove helpful in showing the lower ureters and bladder.

Urethrocystography.—As the name implies, a urethrocystogram is a roentgenogram showing the urethra and urinary bladder after retrograde injection of contrast material (air, opaque medium or both). Both anteroposterior and oblique projections are used to advantage in this procedure. Delayed cystograms are sometimes obtained by having the patient retain opaque medium in the bladder for periods of from one to three hours. This procedure, especially important in children with unexplained recurrent urinary tract infection, may show reflux into one or both ureters when conventional cystograms are normal. The damaging effect of reflux on the ureter and kidney by both back pressure and infection has long been known, and the importance of recognizing it cannot be overestimated.

Hysterosalpingography.—This x-ray procedure consists of stereoscopic anteroposterior exposures of the pelvis following injection of iodized oil into the uterine cavity and oviducts (Plate 81, *A*, p. 269). Injection is done under careful fluoroscopic control. In many instances 24 hour check-up films are necessary to evaluate tubal patency in cases of sterility.

Two less frequently used diagnostic procedures have gained considerable favor in recent years and are deserving of mention—presacral pneumography and translumbar aortography.

Presacral pneumography.—The value of direct perirenal injection of air in various renal, adrenal and other retroperitoneal abnormalities has been recognized for years, but its use was greatly restricted because of the very real danger of fatal air embolism emanating from the highly vascular perirenal tissues. This objection was partially overcome in 1947 when Rivas first described a method whereby air injected into the relatively avascular presacral areolar tissue would readily dissect into the

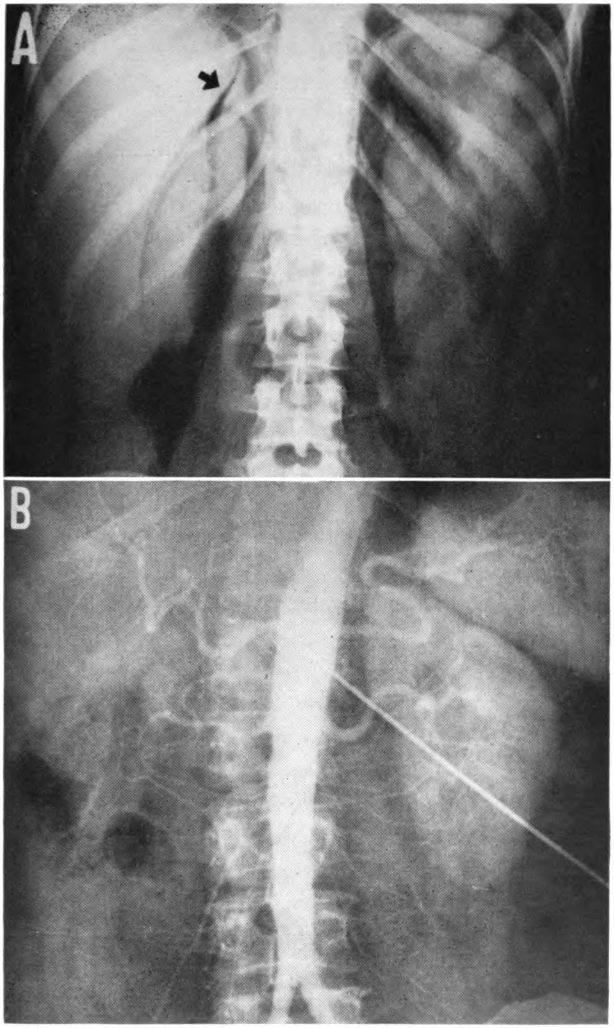


PLATE 77.—*A*, normal retroperitoneal structures outlined by air following presacral pneumography. Right adrenal (arrow) shows up especially well. *B*, translumbar aortogram. Normal left renal artery and opacified left kidney (nephrogram) contrast sharply with diminished vascularity of atrophic right kidney. Large gauge needle enters aorta midway between celiac axis and renal arteries.

retroperitoneal space, producing sharp delineation of the kidneys and adrenals, such as is shown in Plate 77, *A*. Although much safer than direct perirenal air injection, thus permitting injection of much larger quantities of air, presacral pneumography is not entirely without danger. It is encouraging to note, however, that recent substitution of more rapidly soluble gases, such as carbon dioxide or nitrous oxide, for air as the injection medium of choice promises to reduce the incidence of gas embolism to the vanishing point. In any event, either perirenal or presacral pneumography should be employed only when more conventional diagnostic procedures fail to show a suspected adrenal tumor, renal tumor or perirenal abnormality.

Translumbar aortography.—Opacification of the abdominal aorta and its branches by direct injection of contrast medium via the translumbar route was introduced as a diagnostic procedure by dos Santos, a Portuguese urologist, more than twenty years ago, but only recently has it achieved widespread acceptance. Enthusiasts proclaim it the perfect urologic diagnostic procedure because of the spectacular manner in which the opacified vascular pattern of the renal parenchyma (nephrogram) reflects the presence or absence of disease (Plate 77, *B*). If the nephrogram fails to show suspected abnormality, it may appear on the ensuing pyelogram which is obtained a few minutes later when the contrast medium is collected in the kidney calices and pelves. This double-barreled diagnostic approach makes aortography unquestionably the most precise method of recognizing and differentiating renal tumors and cysts.

Despite its obvious advantages, translumbar aortography, like all other radiographic procedures, has definite limitations. There is potential danger of serious complications, but to date the procedure has proved to be surprisingly safe.

Although translumbar aortography was planned primarily for urologic diagnosis, the initial enthusiasm of many urologists has faded, and the procedure is now being used more effectively in the direct detection of such abnormalities of the aorta and its branches as aneurysms, occlusive endarteritis and arteriovenous fistulas. (See Chap. 6, Plate 59, *C* and *D*, p. 204).

THE KIDNEY AND URETER

The variability to be expected in the gross anatomic features of the kidneys is well known. On the other hand, it is probable that, until one has begun to scrutinize the pyelographic silhouettes of renal pelves and calices, one will not realize that an individual can be unmistakably identified by the detailed pattern of his renal cavities. Variations in size and shape and in the number of major and minor calices are infinite.

In general, the roughly triangular pelvis is continuous at its apex with the ureter. The major calices arise from the base of the pelvic triangle. Ordinarily an upper, a middle and a lower major calix can be seen; the middle is absent in some cases. Each major calix is subdivided peripherally into minor calices, six to 12 in number. Normally, when filled with contrast material, the latter appear as delicate, sharply defined, cup-shaped shadows. Loss of these characteristics strongly suggests renal disease. Incidentally, when a calix is projected "end on," it casts a ringlike shadow that is less dense at its center where the tip of the renal pyramid displaces the contrast material. These normal pyelographic features can be observed in Plate 76.

Ureteral caliber and length are variable, but the course followed by the ureters is fairly constant in relation to the spine and the bones of the pelvis (Plate 76). It is common to find some luminal narrowing at the ureteropelvic and ureterovesical junction points.

ANOMALIES. Renal malformations are surprisingly common. Although some of the gross types may sometimes be recognized in scout films, pyelography is necessary for detection in most instances, and this form of x-ray examination is invaluable if developmental anomalies are to be evaluated accurately. Renal hypoplasia, congenital absence of one kidney and fusion of the kidneys belong in the category of malformations which may be diagnosed without the benefit of pyelography.

"Horseshoe kidney," or fusion of the kidneys at the lower poles, produces pathognomonic pyelographic signs. In Plate

78, *A*, neither kidney has fully rotated to the normal position which is parallel to the vertical transverse plane of the body. The lower poles, connected by an isthmus of soft tissue crossing the spine, are directed medially; the upper poles, laterally. Both ureters in their upper portions are displaced laterally.

Commonplace duplication anomalies of kidney or ureter can be identified with certainty only when pyelography is used. This type of malformation may occur in a variety of degrees, unilaterally or bilaterally (Plate 78, *B*). Because injection of the upper urinary tract by the retrograde method may result in the delineation of only one part of a duplicated ureter or kidney (*C*), excretory pyelograms are more reliable when the possibility of duplication is being investigated.

Differentiation between renal ptosis and renal ectopy can be accomplished by observing the length of the ureter on the affected side. In ptosis the ureter is of normal length; whereas a congenital ectopic kidney invariably has a short ureter (Plate 78, *D*).

CALCULI. Most urinary calculi (over 90 per cent) contain sufficient calcium to render them visible on survey films. The relatively small number of stones which are nonopaque to x-rays consist largely of uric acid and cystine combined with bacteria and cellular debris.

In all instances of suspected nephrolithiasis it is advisable to use pyelography not only to observe the precise location of the calculi but also to determine whether or not visible evidence of renal or ureteral damage has been produced by these concretions. This is especially important if surgical removal of the stones is contemplated.

Renal calculi must be differentiated from gallstones, calcified abdominal lymph nodes and phleboliths, as well as from less common forms of intra-abdominal calcification. Stereoscopic exposures and oblique projections frequently are helpful. Occasionally, an opaque calculus may grow so large that it forms a cast of the entire renal cavity. Such a concretion, commonly called a "staghorn" calculus, may be mistaken for an unusually dense pyelogram if no preliminary survey examination is made.

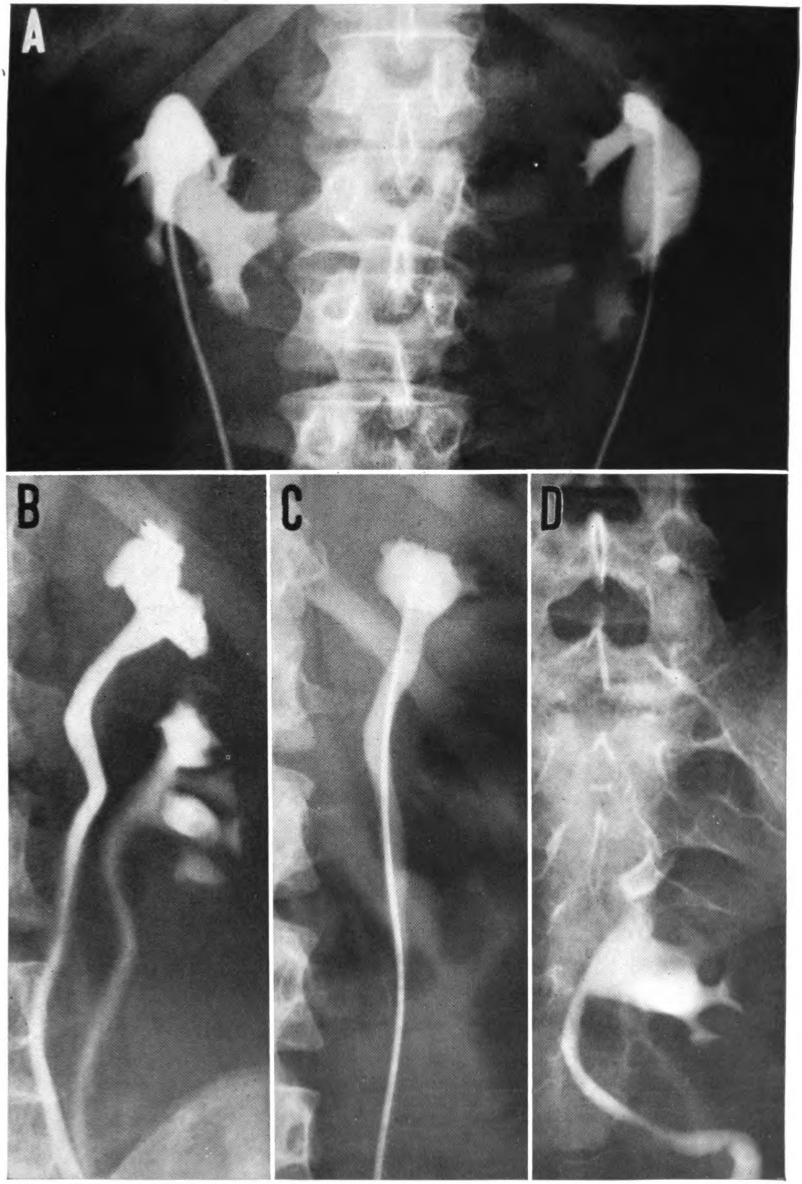


PLATE 78.—*A*, horseshoe kidney. *B* and *C*, duplication anomalies. *D*, ectopic kidney.

Paradoxically, these large stones are apt to produce fewer symptoms than those which are small enough to be extruded into the ureters.

Interval filming helps to demonstrate the progressive descent of renal and ureteral calculi. Plate 79, *A*, shows a relatively large opaque calculus in a lower pole calix of the left kidney and an even larger stone in the upper portion of the left ureter. Pyelograms one week previously had disclosed the larger calculus in the left kidney pelvis. Because the stone was too large to pass farther down the ureter, ureterolithotomy was eventually performed.

HYDRONEPHROSIS AND HYDROURETER. Abnormal dilatation of the renal pelvis and calices (hydronephrosis) and dilatation of the ureter (hydroureter) may be produced by persistent but incomplete obstruction at a significant point in the urinary tract. The pronounced hydronephrosis seen in Plate 79, *B*, is due to constriction by an aberrant artery of the pelvis of the left kidney near the ureteropelvic junction.

The mild forms of pathologic renal and ureteral dilatation may be difficult to detect roentgenologically because of wide variation in normal size. Flattening or clubbing of the cup-shaped ends of the minor calices and broadening of the infundibula represent the earliest signs of hydronephrosis, although they are seldom diagnostic in themselves. More severe degrees of dilatation are clearly evident on pyelograms (Plate 79, *B*), although occasionally the opaque medium may be so markedly diluted by the urine that much of its contrasting density is unfortunately lost.

The use of roentgen methods has shown that transient physiologic hydronephrosis of moderate degree occurs in pregnancy owing to partial ureteral obstruction by the enlarged uterus. This condition promptly corrects itself following involution of the uterus.

NONSPECIFIC INFECTION. Acute, hematogenous renal infection by pyogenic cocci produces no roentgenologic signs unless one of the complications, such as carbuncle or perinephric abscess, develops. A renal carbuncle is formed when multiple

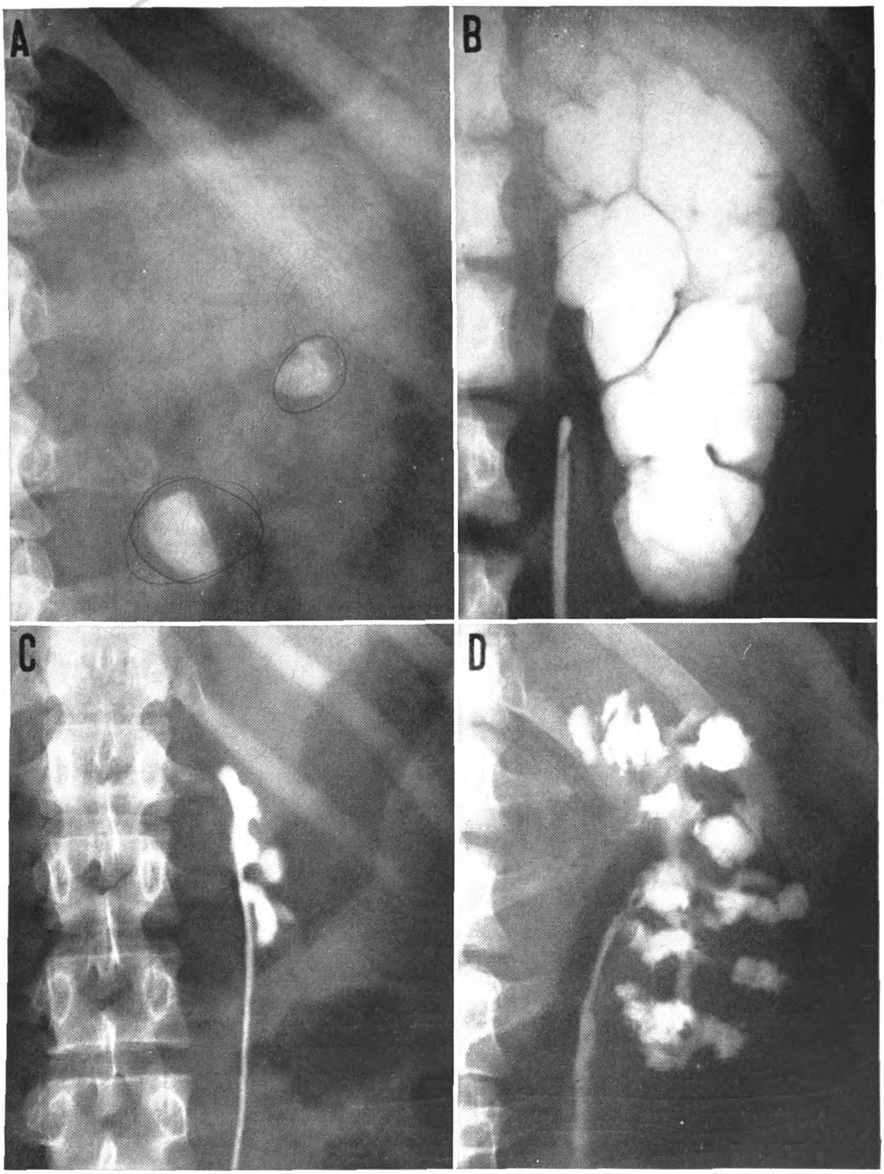


PLATE 79.—*A,* calculi. *B,* hydronephrosis. *C,* contracted kidney; chronic pyelonephritis. *D,* tuberculosis.

tiny areas of suppuration coalesce to form large abscesses. Such abscesses are prone to communicate with the renal pelvis, and in these instances pyelograms can be used to outline the irregular abscess cavities. Complete or partial obliteration of renal and psoas shadows on the side of the lesion, lateral curvature of the spine with concavity toward the affected side and fixation of the involved kidney and perirenal structures are diagnostic signs of perinephric abscess. The last of these can be shown by pyelographic exposure during respiration; the pyelogram on the normal side is blurred by motion, whereas on the involved side it is clear because the parts are motionless.

Chronic pyelonephritis, usually due to bacillary infection, may be clearly evident on the basis of clinical and laboratory manifestations in the face of entirely normal pyelographic findings. Unless the pathologic changes in the kidney have materially narrowed the channels (infundibula) by which the major and minor calices are connected, the characteristic signs of clubbed minor calices and unduly slender infundibula will not be seen in pyelograms. Eventually, in long-standing pyelonephritis, the proliferation of scar tissue produces a small, contracted kidney (Plate 79, *C*). At this stage x-ray findings are similar to those in congenital renal hypoplasia or to late results of prolonged glomerulonephritis.

TUBERCULOUS INFECTION. At the outset, or at least early in the disease, renal tuberculosis involves one of the papillae through which urine escapes into a minor calix. If, owing to progressive caseation, the lining of the calix ruptures, the tuberculous abscess, even though small, may be detected by retrograde pyelography. Frequently, the infection spreads rapidly throughout the renal parenchyma to involve in similar fashion the pelvis and upper part of the ureter. Again, sites of involvement are recognizable in pyelograms as irregular, "motheaten" zones of renal destruction (Plate 79, *D*). Positive identification of lime salt deposits within the renal cortex or medulla strongly suggests tuberculous infection. Such deposits must be differentiated from urinary calculi and from the diffuse bilateral renal calcinosis of hyperparathyroidism.

TUMORS. Benign neoplasms of the kidney are rare and are seldom of clinical importance. Malignant tumors occur for the most part during early childhood or in late middle age. In the juvenile group, tumors are of the mixed embryoma type (Wilms' tumor); whereas hypernephroma predominates at the later age. The onset of these lesions is notoriously insidious; and by the time roentgenologic assistance is sought, tumors are relatively large and capable of producing well-defined pyelographic signs. With or without detectable distortion of kidney shape or evidences of a diffuse abdominal mass, elongation, separation and narrowing of renal calices on the involved side are characteristic features. In an appreciable number of renal embryomas and hypernephromas calcium deposits will be clearly visualized.

Papillary carcinomas represent about one tenth of all malignant kidney tumors. These have their origin in the lining of the renal pelvis and are seen in pyelograms as rounded or scalloped filling defects in the injection mass. They must be differentiated from blood clots and from those infrequent calculi which are nonopaque.

A solitary cyst of the kidney cannot be differentiated from neoplasm on the basis of roentgen findings alone, but the distinction is of importance only from a preoperative prognostic point of view. Multiple congenital cysts (polycystic disease) are much more common than solitary cysts; and, because they are almost always bilateral, the roentgen appearance of enlarged kidneys, distorted pelves and elongated calices is practically pathognomonic of the condition (Plate 80, *A*).

THE BLADDER, PROSTATE AND URETHRA

The normal bladder, when distended by urine, can be identified at times on a plain roentgenogram of the pelvis, but for accurate evaluation it is necessary to replace the urine with some form of artificial contrast medium. The distended bladder is seen as a perfectly smooth, round or oval structure about 15 cm. in diameter usually located deep in the pelvis anterior to the rectum.

ANOMALIES. Exstrophy, epispadius and hypospadius are recognized roentgenologically not by any deformity of the bladder or urethra but rather by the wide separation of the pubic bones which frequently accompanies these congenital vesical defects.

FOREIGN BODIES. Any foreign material capable of being inserted into the urethra may find its way into the bladder. Metallic objects can be readily identified on survey films. Both opaque and nonopaque objects may serve as a favorable nidus for stone formation and may be recognized months or years after their insertion by their calcium-encrusted periphery. Plate 80, *B*, illustrates a pipe cleaner in the bladder and prostatic urethra. That portion of the foreign body which projects into the bladder is deeply imbedded in a large, round, opaque vesical calculus.

CALCULI. Bladder stones, some of which have their origin in the kidney, are typically large, solitary, round or oval, laminated concretions which can be identified on survey films because of their calcium content (Plate 80, *B*). The findings are by no means constant. A fairly large group of nonopaque calculi is demonstrable only on injection of contrast material. Many vesical calculi are associated with infection and commonly occur in patients with some form of partial obstruction in the lower urinary tract.

[The Bladder, Prostate and Urethra *continued on page 266.*]

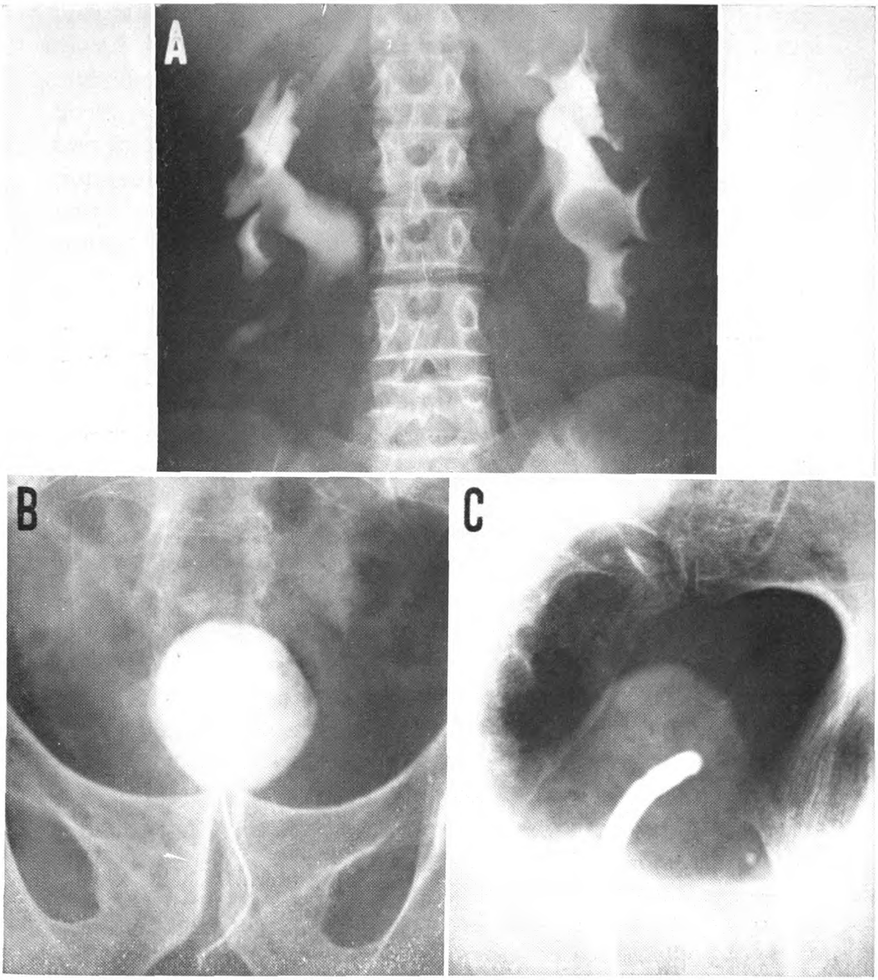


PLATE 80.—*A,* bilateral polycystic kidneys. *B,* pipe cleaner embedded in large vesical calculus. *C,* moundlike intravesical protrusion of hypertrophic prostate gland as seen in oblique air cystogram; urethral catheter in place.

BLADDER NECK OBSTRUCTION. The interesting findings associated with obstruction at the vesical outlet furnish the urologist with valuable diagnostic information. Sometimes the causative factor may be directly visible. Sometimes recognition of the condition depends on the results which vesical neck obstruction produces. In conjunction with clinical, laboratory and cystoscopic findings, x-ray evidence may have more than diagnostic value; it may materially help to determine prognosis and the planning of treatment.

Benign hyperplasia of the prostate is the most common cause of vesical neck obstruction. The first visible effect of this or of any other type of chronic obstruction, best observed in cystograms, is marginal irregularity of the bladder shadow known as trabeculation. This is a manifestation of the attempt on the part of the bladder to combat gradually increasing occlusion of the vesical neck. Hypertrophy of muscular elements in the bladder wall is reflected in the protrusion of bands into the bladder lumen. Later, as both the cause and the effects of obstruction become progressively more pronounced, true diverticula develop at relatively weak points in the bladder wall owing to greatly increased intravesical pressure. When filled with opaque medium, these abnormal pouches, which are connected with the main cavity of the bladder, appear as dense globular shadows extending from the bladder wall.

Intravesical protrusion of the hyperplastic prostate is seen to best advantage in oblique projections against a background of air injected into the bladder. By using this technic, the approximate size of the enlarged prostate can be determined. The moundlike shadow at the base of the bladder shown in Plate 80, *C*, represents moderate intravesical protrusion of an enlarged prostate. Anterior displacement of the catheter indicates that in this instance the hyperplastic process is primarily restricted to the median lobe of the gland.

Carcinoma of the prostate may produce bladder changes similar to those of benign hyperplasia but the signs, if present, are usually less well defined.

Bladder neck obstruction in children may occur as the result of a constricting band of hypertrophied muscle around the blad-

der outlet or by so-called congenital urethral valves which are folds of redundant mucosa that partially or completely obstruct the outlet or the posterior urethra. Back pressure may be so pronounced that tremendous dilatation of not only the bladder but also the ureters and renal collecting systems (pelves and calyces) may occur. Cystography and, to a lesser extent, pyelography are invaluable in analyzing the devastating secondary effects of these important lesions. An ingenious method of voiding cystourethrography recently developed in Sweden indicates that, if desired, the obstructing lesions themselves may be demonstrated.

MISCELLANEOUS CONDITIONS. Among the other abnormalities of bladder and prostate which may be demonstrable on roentgenologic examination, three deserve mention. Primary tumors of the bladder can be identified in cystograms as nonopaque filling defects fixed in relation to the vesical wall. In chronic cystitis the bladder is small and contracted, and often denser than normal, on survey film examination. A cluster of small discrete shadows of great density projected just behind the symphysis pubis and directly below the bladder, if that structure can be identified in the film, can be confidently interpreted as prostatic calculi.

The urethra can be shown satisfactorily in roentgenograms prepared during the injection of opaque medium by way of the external urethral orifice. Good results follow the use of a viscous jelly impregnated with sodium iodide in 12½ per cent solution. This type of injection mass will remain in the urethral lumen without escaping into the bladder sufficiently long to fill the tubular cavity in its entirety during x-ray exposure. It is convenient to combine urethrography with cystography for the purpose of investigating all portions of the lower urinary tract.

Benign prostatic hypertrophy is the commonest significant abnormality demonstrable by this approach. Selective enlargement of the lateral lobes of the gland produces flattening of the lumen of the prostatic urethra in ribbon-like fashion and considerable increase in anteroposterior diameter. Median lobe hyperplasia, if it is sufficiently pronounced, results in character-

istic anterior angulation of the proximal portion of the urethra.

Infection is the most common cause of urethral stricture, although the lesion may result from direct trauma. Regardless of etiology, urethral strictures can be located and their extent and degree determined by means of urethrography. If, as sometimes occurs, stricture is associated with a foreign body, a periurethral abscess or a diverticulum, this form of exploration adds materially to the information which can be obtained by nonradiologic methods of examination.

THE FEMALE GENITAL TRACT

One of the most valuable applications of roentgenology to the field of obstetrics and gynecology is its use in the determination of the degree of tubal patency in cases of sterility. The technic of hysterosalpingography, by which the lumens of the uterus and oviducts are visualized, has already been briefly described. This procedure is also of value in the identification of various abnormalities in the female genitalia. For example, Plate 81, *B*, illustrates the typical appearance of a bicornuate uterus in a patient who had had one previous normal delivery but who subsequently could not become pregnant. Additional congenital anomalies, malposition of the uterus and uterine polyps are some of the other abnormalities which may be shown by this method.

A plain survey film of the abdomen and pelvis may show radiolucent fat and a well-formed tooth within an ovarian cyst or the characteristic pattern of calcium deposition in a longstanding uterine fibroid.

Numerous ingenious adaptations of the principles of roentgen diagnosis have been devised to measure maternal pelvic diameters more accurately than is possible by ordinary obstetric methods. Appreciable success has been achieved, although it has not been possible to eliminate all sources of error. Roentgen pelvimetry has met with opposition by radiologists and obstetricians alike, largely because accuracy depends on exacting technic and specialized equipment. There can be no doubt, however, that it has an important place in those instances in which clinical measurements that suggest the imminence of

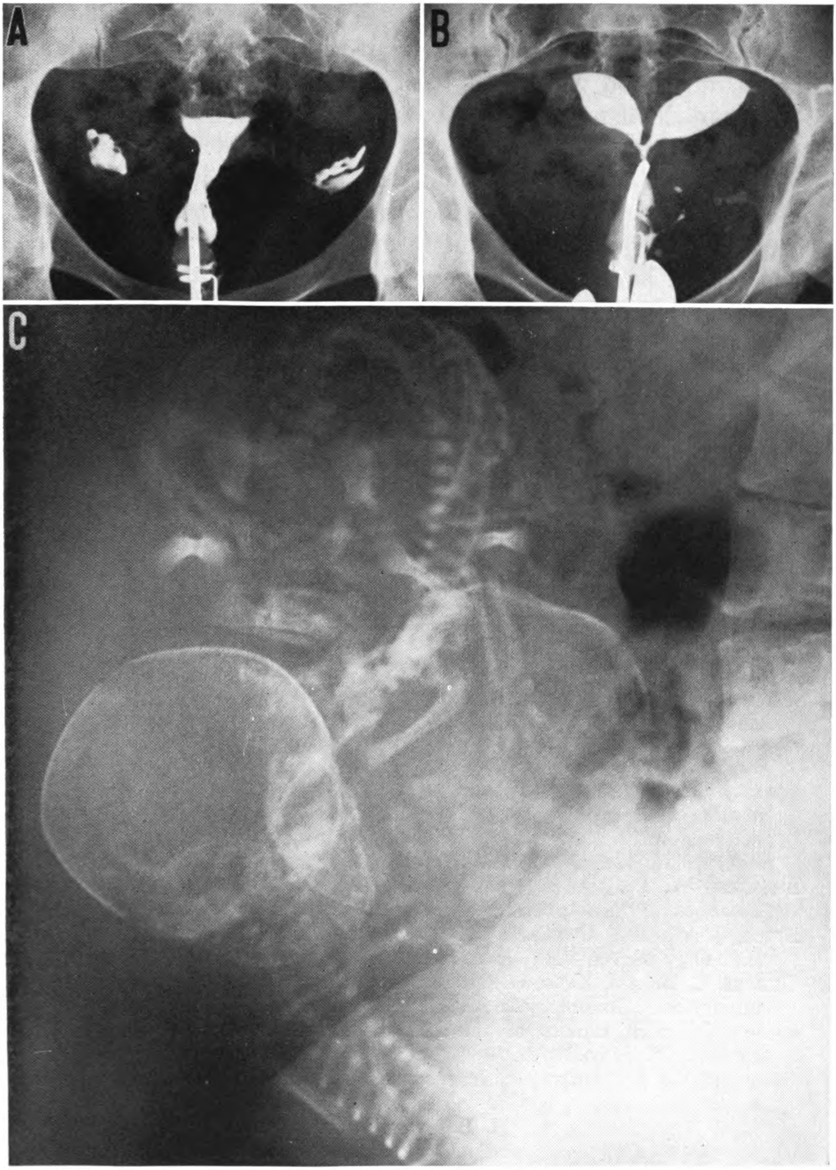


PLATE 81.—*A*, normal hysterosalpingogram. *B*, bicornuate uterus. *C*, twin pregnancy.

difficult delivery are inconclusive. It is helpful to be able to demonstrate that pelvic proportions are entirely adequate in pregnant women who report that spontaneous delivery proved to be impossible on some previous occasion.

Study of the fetal skeleton in utero enables the examiner to determine both the size of the fetal head with considerable accuracy and its relation to the maternal pelvic structure. After the fourteenth week of gestation fetal age can be estimated on the basis of bone measurements. This, together with other fairly reliable signs, is often of great value in determining whether or not fetal death has occurred. Certain congenital anomalies of the fetus can be recognized roentgenologically before delivery—no small service to the obstetrician and his patient. On occasion, the radiologist can determine with considerable accuracy the location of placental attachment. This information is valuable, of course, when placenta praevia is suspected. The positive identification of multiple pregnancies, such as the twins illustrated in Plate 81, *C*, is a fairly commonly experienced and generally gratifying result of the x-ray examination of obstetric patients.

READING LIST

BAKER, W. J.: Anomalies of the urinary tract, Am. J. Roentgenol. 43:636–648, May, 1940.

BELL, J. C.; HEUBLEIN, G. W., AND HAMMER, H. J.: The roentgen examination of the urinary tract with special reference to methods of examination and findings in individuals with testicular tumors, Am. J. Roentgenol. 53:527–562, June, 1945.

BRAASCH, W. F., AND EMMETT, J. L.: *Clinical Urography—An Atlas and Textbook* (Philadelphia: W. B. Saunders Company, 1951).

BUICE, J. W., AND GOULD, D. M.: Abdominal and pelvic pneumography, Radiology 69:704–710, November, 1957.

GILLIES, C. L., AND KERR, H. D.: Roentgen diagnosis of lesions of the lower urinary tract, Radiology 26:286–294, March, 1936.

——: Malignant tumors of the kidneys in adults, Am. J. Roentgenol. 43:629–635, May, 1940.

GROSS, R. E.: *The Surgery of Infancy and Childhood* (Philadelphia: W. B. Saunders Company, 1953).

HAAS, R. L.; LATOURETTE, H. B., AND WHITEHOUSE, W. M.: Clinical applications of obstetric radiology, Surg., Gynec. & Obst. 99:462–468, October, 1954.

HODGES, P. C.: Roentgen pelvimetry and fetometry, Am. J. Roentgenol. 37:644–662, May, 1937.

HODGES, P. C., AND NICHOLS, R. L.: Orthographic pelvimetry, Radiology 53:238–247, August, 1949.

KERR, H. D., AND GILLIES, C. L.: *The Urinary Tract: A Handbook of Roentgen Diagnosis* (Chicago: Year Book Publishers, Inc., 1944).

KJELLBERG, S. R.; ERICSSON, N. O., AND RUDHE, U.: *The Lower Urinary Tract in Childhood* (Chicago: Year Book Publishers, Inc., 1957).

MARSHAK, R. H.; POOLE, C. S., AND GOLDBERGER, M. A.: Hysterography and hysterosalpingography, Surg., Gynec. & Obst. 91:182–192, August, 1950.

RIVAS, M. R.: Roentgenological diagnosis: Generalized subserous emphysema through a single puncture, Am. J. Roentgenol. 64:723–734, November, 1950.

SMITH, P. G.; EVANS, A. T.; ELSEY, E. C., AND FELSON, B.: Translumbar arteriography: Its roentgenologic interpretation, Am. J. Roentgenol. 67:183–196, February, 1952.

SNOW, W.: *Roentgenology in Obstetrics and Gynecology* (Springfield, Ill.: Charles C Thomas, Publisher, 1952).

STEWART, C. M.: Delayed cystography and voiding cystourethrography, J. Urol. 74:749–759, December, 1955.

WESSON, M. B.: *Urologic Roentgenology* (Philadelphia: Lea & Febiger, 1950).

WHITEHEAD, A. S.: Determination of placental site by soft tissue radiography, J. Fac. Radiologists 4:245–263, April, 1953.

PART II

Therapeutic Radiology

9

General View of Therapeutic Radiology

Introduction

IN THERAPEUTIC radiology the student encounters a field of medical practice which is defined on the basis of the agents employed in the treatment of disease. Such a delimitation of a medical specialty is certainly not unique, since surgery and internal medicine are essentially established on like grounds. The therapeutic weapons of radiology now available are x-rays and the radiations of radium and certain radioactive isotopes. As will be seen, these radiations are utilized in a variety of heterogeneous disorders of the human body ranging from simple inflammations to malignant neoplastic conditions.

It is not the nature of the disease processes but the singular characteristics of the radiations directed against these processes that unifies radiation therapy. The production and control of the radiations call for specialized knowledge and skills involving basic understanding of their physical nature. Specialized training is required to learn to produce and to gage the interaction of radiation and the tissues of the body in order to develop the reactions that are essential in bringing about the desired response. This may consist of a tissue reaction to overcome an inflammatory process, the depression of a glandular function or the destruction of a malignant growth.

Although technical considerations have created it, modern

therapeutic radiology involves much more than a skeleton of technic. To treat disease one must know disease. This applies to radiology as rigorously as to any field in medicine. To know disease one must be familiar with its clinical manifestations, since recognition, that is, diagnosis, is a primary requisite. Also essential is knowledge of the natural history of disease—the way it starts, how it develops, how it extends, and so on. Such aspects as the pathologic, roentgenologic and others may be of vital importance in determining the type and vigor of irradiation. The advent of radiology in the field of therapy has developed a new body of information concerning the interaction of normal and diseased tissue and absorbed radiation; the clinical expressions of these interactions constitute a field of clinical medicine of obvious importance to the radiologist. Due consideration must be given to the patient as a whole with respect to indications for intervention by means of irradiation; the patient's general condition and his anticipated tolerance of radiation both locally and systemically must be taken into account. More is expected of the surgeon than the achievement of technical skill: diagnostic ability and surgical judgment are considered of paramount importance. Likewise, he who would employ radiation as a form of therapy must develop diagnostic acumen and the radiation-counterpart of surgical judgment.

The scope of radiation therapy in contemporary medicine is broad. Almost every specialty in medicine calls on the radiologist, at one time or another, for assistance in the treatment of diseases encountered in its domain. The case material of therapeutic radiology is found in virtually every field of medicine. Malignant neoplasms of the tonsil, pharynx and larynx come from otolaryngology. The leukemias, other lymphoblastomas and thyroid disease come from internal medicine. Mammary carcinomas, among many others, are referred by the general surgeon. For the thoracic surgeon, certain tumors of the chest are irradiated. In urology some tumors of the bladder and the kidney are in whole or in part radiation problems. The role of radiation treatment in certain gynecologic conditions is one of first-rank importance. The worker in arthritic diseases depends on irradiation

for symptomatic relief for patients having several common conditions. There are intracranial conditions in which the value of irradiation may exceed what the neurosurgeon has to offer. The widespread use of radiation in dermatologic conditions is common knowledge. For the pediatrician the radiologist treats hemangiomas, as well as a variety of malignant neoplasms that occur early in life. Many more examples could be given of other diseases both in the fields here mentioned and in other fields as well.

That radiation treatment is utilized in malignancy is generally known, although the importance of its role may be poorly understood. However, the usefulness of irradiation in nonmalignant diseases is frequently overlooked. A partial listing demonstrates a diversity of conditions which may be treated by irradiation: menopausal bleeding, cavernous hemangioma, polycythemia vera, furuncle, tuberculous adenitis, conduction deafness, spondylitis rhizomelique, salivary gland fistula and acute postpartum mastitis.

Useful as the radiation treatment of these nonmalignant conditions may be in medical therapy, today the prime significance of the application of radiation in disease is found in its ability to destroy certain types of malignant tumors. Cancerous lesions constitute one of the outstanding medical problems of the day, and the importance of this problem is increasing because of the rapidly rising proportion of persons in the older age groups in which cancer takes its greatest toll. The remarkable success in the control of the infectious diseases is responsible for the changing character of the population. Malignant neoplasms were listed about ninth among the causes of death in the United States in 1900; by 1933 they had reached second place and have remained there. In 1942, 163,400 deaths due to cancer were reported, and in 1950 this figure rose to approximately 210,000.

Modern medicine has only two ways of eradicating the malignant neoplasms: those of surgery and those of therapeutic radiology. The human body has no significant natural defenses against malignancies once they develop, and sooner or later with rare exceptions death will ensue unless surgery or irradiation can

be successfully carried out. The applicability of surgical methods and that of radiation methods do not coincide. There are tumors which can be eradicated only by excision, but there are neoplasms which can be cured only by radiation methods. For some lesions either surgery or radiation can be used with good results; in others, though either may be used, one may be superior to the other. Even in the same type of tumor one may find that, at different stages of the disease, the best method of treatment may change from surgery to irradiation or the reverse. With some tumors various combinations of the two may be required to obtain the best results.

The advent of irradiation in cancer therapy has extended the potentiality of successful treatment of the malignant tumors. If radiation therapy were not available, the yearly death toll of cancer would considerably exceed the currently reported figures. Even when total eradication is not possible, irradiation often can offer the patient relief of pain and increased length of life under comfortable conditions that may be obtainable in no other way. Indeed, proper management of many incurable neoplasms may accomplish at least as much as modern care of arteriosclerotic and rheumatic heart disease and other incurable illnesses.

In directing radiation against the tissues of the body, the physician is employing an agent capable of causing great damage. Radiation is primarily a destructive agent exerting a deleterious effect on normal cellular processes which, if severe enough, becomes irreversible and leads to death of the cell. When treating diseases which are not dangerous to life, or are self-limiting, the radiologist carefully stays within such limits of dosage as will avoid all harmful effects. In the treatment of malignant neoplasms, to achieve complete eradication dosage *must* be high and tissue reactions may become severe. The discomfort of these reactions, as well as certain permanent tissue alterations, is accepted as part of the price that must be paid to give the patient his best chance of cure. Reasonable operative mortality rates and degrees of mutilation are considered justifiable in radical surgical procedures when the alternative is death. The same attitude must be applied to the risk of complications encountered in properly executed high-dose radiation

treatment. Undertreatment to avoid complications is poor treatment and only deprives the patient of his chance for recovery.

The constantly changing character of radiation methods has been a prominent feature in their development. In part this has been due to empiric trial-and-error search for efficient modes of administration of the radiations. The steady improvement in the technical features of the apparatus for the production of radiation has been reflected inevitably in the modes of clinical application. Increasing knowledge of the physical characteristics of the radiations also has played its part in changing the technics and capabilities of clinical radiation treatment. Information concerning the interaction of radiation and living tissue gained by experimental work and clinical observation has altered many of our earlier concepts of how, when and where to employ radiation.

Radiation is an important agent in the battle against the cancerous diseases, but radiation alone has never cured a patient. It is not radiation but *radiation efficiently applied* that leads to successful therapy in malignancies. Mere exposure to one or another of the kinds of radiation available today will not give satisfactory results. Radiation therapeutic programs must be planned and must be based on the skill, knowledge and experience of capable physicians who concentrate their efforts on this type of work. A properly organized and completely equipped clinic is essential, as is close co-operation with competent workers in surgery and pathology.

As has been indicated, the scope of radiation treatment is broad and the diseases in which it is applicable are numerous and diverse. Prime interest centers on its role in cancer; however, cancer is not the name of a single disease but a collective term which includes multiple neoplastic entities of variegated clinical and pathologic pictures. The treatment of these conditions cannot be taken up without discussion of the characteristics of each, but obviously it is beyond the scope of this book to deal with them in a comprehensive and detailed manner. Such information must be acquired from courses in medicine, the surgical specialties and pathology, or by collateral reading. In some conditions certain general aspects will be considered, in

others the discussion will be limited to features important for radiologic management and in still others only problems of irradiation will be taken up.

The radiation treatment of dermatoses and dermatitides is not discussed. Irradiation is of value in this field, but diagnosis and indications are more important than administration of the radiation and are best handled by the dermatologist. Material on this subject can be found in most texts on dermatology.

On the broad canvas of clinical radiation therapy only a few strokes can be brushed in and a few highlights depicted; the reader must bear this in mind when he reads the clinical section. He must also realize that many of the problems of radiation treatment are far from solved. The gaps in our knowledge are broad and in many situations controversy exists. The physical foundations of radiology involve fields of pure and applied modern physics concerning which much has been written. It is obviously not possible to take up these aspects in any detail. Indeed, detailed exposition is necessary only for those who wish to qualify as practitioners of radiation therapy. The student's objective should be the acquisition of a general view of radiation in its clinical application.

READING LIST

Sources of information regarding clinical manifestations of malignant disease and on radiation treatment are:

ACKERMAN, L. V., AND DEL REGATO, J. A.: *Cancer: Diagnosis, Treatment and Prognosis* (2d ed.; St. Louis: C. V. Mosby Company, 1954).

CADE, S.: *Malignant Disease and Its Treatment by Radium* (2d ed.; Baltimore: Williams & Wilkins Company; 4 volumes, 1948-1952).

CANTRIL, S. T.: *Radiation Therapy in the Management of Cancer of the Uterine Cervix* (Springfield, Ill.: Charles C Thomas, Publisher, 1950).

CARLING, E. R.; WINDEYER, B. W., AND SMITHERS, D. W.: *Practice in Radiotherapy* (St. Louis: C. V. Mosby Company, 1955).

HURDON, E.: *Cancer of the Uterus* (New York: Oxford University Press, 1943).

PATERSON, R.: *The Treatment of Malignant Disease by Radium and X-rays* (London: Edward Arnold & Company, 1948).

PORTMANN, U. V.: *Clinical Therapeutic Radiology* (New York: Thos. Nelson & Sons, 1950).

WAY, S.: *Malignant Disease of the Female Genital Tract* (New York: The Blakiston Company, 1951).

An excellent small volume on general radiation biology is:

SPEAR, F. G.: *Radiations and Living Cells* (New York: John Wiley & Sons, Inc., 1953).

More comprehensive and detailed information on radiation biology is to be found in:

ELLINGER, F.: *Medical Radiation Biology* (Springfield, Ill.: Charles C Thomas, Publisher, 1957).

The pathology of neoplasms is treated in various standard texts on pathology, but the following are of special value:

EWING, J.: *Neoplastic Diseases: A Treatise on Tumors* (4th ed.; Philadelphia: W. B. Saunders Company, 1940).

NOVAK, E.: *Gynecological and Obstetrical Pathology* (Philadelphia: W. B. Saunders Company, 1940).

WILLIS, R. A.: *Pathology of Tumors* (St. Louis: C. V. Mosby Company, 1948).

——: *The Spread of Tumors in the Human Body* (London: Butterworth & Company, 1952).

Any of the recent texts on physics gives the picture of atomic and nuclear structure, although in many the development is more detailed than is necessary for our purpose. Such matters as the production of x-rays, x-ray equipment, radioactivity and radium dosage are discussed in a number of books, but the most useful are:

GLASSER, O.; QUIMBY, E. H.; TAYLOR, L. S., AND WEATHERWAX, J. L.: *Physical Foundations of Radiology* (2d ed.; New York: Paul B. Hoeber, Inc., 1952).

JOHNS, H. E.: *The Physics of Radiation Therapy* (Springfield, Ill.: Charles C Thomas, Publisher, 1953).

NATURE AND PRODUCTION OF X-RAYS, RADIUM AND RADIOACTIVE ISOTOPES

The tools of therapeutic radiology are x-rays, the radiations of radium and some radioactive isotopes; these have the ability to penetrate matter and thus can deliver energy into tissue. X-rays are man made; radium is found in nature. X-rays constitute a portion of the electromagnetic wave spectrum, along with light, ultraviolet and infra-red radiations and radio waves, and are characterized by their wavelength or photonic energy. Radium is one of the heavy metals (atomic weight 226), is obtained by extraction from pitchblende and is characterized by the instability of its atomic nucleus. At a fixed rate, the nucleus erupts matter and energy appearing as alpha particles, beta particles and gamma rays. Gamma rays are electromagnetic radiations similar to x-rays, whereas emitted particles are bits of matter electrically charged.

To gain some idea of the nature of x-rays, gamma rays, alpha and beta particles and their interactions with tissue, an elementary conception of the structure of the atom is essential. For our purpose a very simple atomic model will suffice. To begin with, the atom is exceedingly small; its diameter is about 10^{-8} cm. Such minuteness may be difficult to grasp. If an atom were as many times larger than a sphere 1 cm. in diameter as it is smaller than such a sphere, it would have a diameter of over 620 miles. The particles of matter making up the atom are arranged in the pattern of a solar system with a heavy central core (the nucleus) and a number of light particles (electrons) revolving about the nucleus in circles or ellipses (orbits). Both nucleus and electrons are very tiny compared with the diameter of the atom so that most of the atom consists of empty space.

This paradox of the lack of matter in matter does not mean that substance has suddenly lost its property of solidity. Rather, this attribute depends much more on the electrical energy of the subatomic particles than on their bulk. Both the nucleus and the electrons are electrically charged, the former positively, the latter negatively. The electrons represent the "atoms" of electricity and enact an important role in the interaction of radiation and matter. The unit electrical charge of an electron is 4.774×10^{-10} electrostatic units and is the smallest amount of electricity obtainable. The electron weighs 9×10^{-28} Gm.

Under normal conditions the positive charge of the nucleus is equal to the number of negative charges of all the orbital electrons, and the atom is electrically neutral. Electromagnetic forces maintain the atom in a stable state; the positive nuclear charge by attraction keeps the electrons in their orbits, and the latter keep apart in space by the repulsion of their like charges. Under certain conditions an electron can be removed from an orbit. This process of dissociation is termed "ionization" and results in the formation of an ion pair consisting of an electron, the negative ion, and the remainder of the atom bearing a net positive charge, the positive ion. Another point to bear in mind is that atoms are linked together by their orbital electrons to form molecules.

The number of the positive nuclear charges characterizes

an element and, of course, determines the number of orbital electrons. Elements exist which have different weights but the same number of nuclear charges—these are called isotopes. Their mass may differ, but they have the same number of nuclear charges and therefore the same number of orbital electrons. Since the orbital electrons determine the chemical properties of elements, isotopes have identical chemical properties.

The nucleus is thought of as being constructed of two types of subatomic particles. One of these is the proton, which carries a positive charge equal to that of an electron and weighs about 1,845 times as much as an electron. Hydrogen, which has a single nuclear charge, contains only 1 proton in its nucleus. The second subnuclear particle is the neutron, which weighs approximately the same as a proton but carries no electrical charge. This characteristic of being electrically neutral has proved of great importance in nuclear physics since such a particle can penetrate into the nucleus of an atom without being subjected to the enormous forces of repulsion that resist the entrance of a positively charged particle.

The atomic nucleus is conceived as consisting of a firmly bound union of protons and neutrons. Heavy hydrogen, which has unit positive nuclear charge and 2 units of mass, has in its nucleus 1 proton and 1 neutron. The helium nucleus, charge 2 and mass 4, contains 2 protons and 2 neutrons; this nucleus is the alpha particle. Copper, which has charge 29 and mass 63, consists of 29 protons and 34 neutrons. The radium nucleus bears a charge of 88 and its mass is 226; in the nucleus are 88 protons and 138 neutrons.

In the production of x-rays electrons play the important role. The phenomena of the interaction of x-rays, gamma rays, beta and alpha particles with living tissue (or other matter) also involve electrons, i.e., orbital electrons. But radiations of radium originate within its nucleus, are products of disintegration of that nucleus and have no relation to phenomena involving orbital electrons. The alpha particle emitted by radium is a piece of its nucleus that has 2 positive charges and a mass of 4 and corresponds to a helium nucleus. The beta particle is an electron (negatively charged) which arises in the process of nuclear dis-

integration (possibly by conversion of a neutron into a proton and an electron); it is not an orbital electron. Gamma rays are radiated from the radium nucleus as it settles down to a more stable state after having undergone one kind of disintegration.

Radium itself actually emits only an alpha particle. Having lost 2 nuclear charges (and 4 mass units), the atom emitting this particle is no longer radium but an element characterized by 86 nuclear charges. This element, a gas, is radon. The series of disintegrations continues, with the emission of an alpha particle at some steps and a beta particle at others until an element of nuclear charge 82, uranium lead, is reached. This element is stable and the radioactive series ceases with it. Gamma rays are radiated at those steps when beta particles are emitted. When radium is used as a therapeutic agent, it is in equilibrium with its disintegration products and the radiations loosely described as coming from radium actually come from all members of this radioactive series. Each individual radioactive substance has its own rate of disintegration which is invariable: that of radium is such that half of any initial quantity will disappear in 1,590 years. In the case of radon the decay rate is such that one half of any initial quantity will be gone in 3.824 days.

Radium in equilibrium with its products emits beta particles of maximum energy 0.65 Mev (radium B), 3.15 Mev (radium C), 0.025 Mev (radium D) and 1.17 Mev (radium E) and a complex spectrum of gamma rays of energies ranging from 0.241 to 2.198 Mev. (Mev = 1 million electron volts; an electron volt is the amount of energy released when an electron falls through a potential difference of 1 volt.)

X-rays are produced by applying high voltages to x-ray tubes. An x-ray tube in principle is a simple electronic tube, highly evacuated, containing a positive and a negative electrode with a filament in relation to the negative electrode (cathode) to supply electrons. When high voltage is applied to the tube electrons leave the cathode and are accelerated at high speed toward the anode (positive electrode). Because of the vacuum the electrons are not impeded by collisions with air atoms. The high-energy electrons strike the anode, are suddenly arrested and

their kinetic energy is transformed into heat with the exception of a small portion which appears as the electromagnetic energy of x-rays.

The beam of x-rays which comes from the x-ray tube is a complicated mixture. It is heterogeneous both in respect to the wavelengths contained in it and in respect to the quantity of each wavelength. The wavelength spectrum of the beam extends from the longest (low energy), which is just able to penetrate the wall of the tube, to a certain minimum wavelength, which is related to the maximum voltage impressed on the x-ray tube. This minimum wavelength is present in small quantity; with increasing wavelength the quantity rises to a maximum and then again falls so that the longest are also present in small quantity. The maximum quantity is nearer to the shortest than to the longest wavelength. The composition of the beam is further complicated by a number of peaks of high quantity made up of the characteristic radiation of the target material; such radiation is derived from disturbances created among the orbital electrons of the target material by the impinging stream of high-speed electrons from the cathode. The general radiation, that is, the noncharacteristic radiation, develops from the varying collision experiences that the accelerated electrons encounter in the target material.

The complicated character of the x-ray beam defies simple description, yet the necessity for describing the kind of beams used in clinical therapy is great. The kind (usually spoken of as the quality) of beam used is an important factor in determining the amount of radiation that reaches a lesion below the surface of the body. To establish a simple index to characterize the quality of a beam of x-rays the quantitative absorption of radiation in matter is utilized. X-rays have been said to be penetrating, but they are not completely so. When passing through matter some of the energy of the radiation is absorbed by collisions with the orbital electrons of the atoms composing the material. If enough material is interposed in the beam, the radiation may be completely absorbed. The biologic effects produced by radiation appear as a result of the energy absorbed by the tissue through which the beam is passing. From a clinical

standpoint the phenomenon of absorption is of basic importance, for the quantity of energy absorbed and its distribution in tissue in large part determine the clinical effects. Thus it appears reasonable and desirable to characterize the quality of the x-ray beam by an absorption characteristic.

In practice, an index termed the half-value layer (h.v.l) is employed. Increasing thicknesses of a given metallic material, such as aluminum or copper, are interposed in the x-ray beam. That thickness of a particular material which absorbs 50 per cent of the initial intensity of the beam is the half-value layer of that beam. The higher the h.v.l., the more penetrating the beam. The half-value layer serves as a fairly accurate indicator of the general or average composition of an x-ray beam. Two beams of the same h.v.l. may be considered to be absorbed in tissue quantitatively in approximately the same way. In practice, the kind of x-ray beam used is specified by stating the voltage applied to the tube, the filtration and the h.v.l.

The composition of an x-ray beam may be varied in two ways: by changing the magnitude and character of the voltage impressed on the x-ray tube and by interposing metallic filters in the path of the beam emerging from the tube. These two factors, voltage and filtration, determine the quality of the x-ray beam. The higher the voltage, the greater the penetrating power of the beam. Passage of the beam through appropriate metallic filters changes its composition in the direction of a higher half-value layer, because the long wavelengths are absorbed to a greater degree than the short ones. Change of the current passing through the x-ray tube has no effect on the quality of the emergent beam.

The amount of radiation produced by an x-ray tube depends on the voltage at which the tube is operated—the higher the voltage, the greater the amount of radiation produced. The quantity of radiation emitted is directly proportional to the magnitude of the current passing through the tube. Filtration exerts an effect on quantity since radiation is absorbed by the filters; the decrease in quantity depends on the kind and thickness of the filtering material.

The amount of radiation present along the axis of an x-ray

beam decreases with increasing distance from the target of the x-ray tube. Since the site of origin of x-rays in an x-ray tube approximates a point, the geometric rule that applies when light is emitted from a point source applies here also, namely, that the intensity of the radiation at a point is inversely proportional to the square of the distance from the point source. Thus at 50 cm. from the target of an x-ray tube one-fourth as much radiation will be present as at 25 cm. This phenomenon is purely a geometric factor and has nothing to do with the quality or absorption characteristics of an x-ray beam or the material through which the beam is passing.

For clinical radiation therapy today, x-rays generated throughout a wide range of voltage are available. For superficial irradiation such as the dermatologist desires for the treatment of dermatitis, x-rays produced at 80,000–100,000 volts (80–100 kv.) are usually employed; most commonly this type of radiation is used without filtration. (The statement of voltage usually means that at some time during the electrical cycle a voltage as high as this is reached; unless specifically described as constant potential, i.e., constant voltage, the voltage wave form is a varying one and depends on the type of generating equipment.) In skin malignancies somewhat higher kilovoltage is generally used, such as 120–140, and bulky lesions may require 200 kv. radiation. Some workers use a special type of x-ray beam generated at about 50 kv. for the treatment of small cutaneous malignancies; the unique feature of this apparatus is the very short distance between the target of the tube and the treated surface.

For a number of years so-called deep x-ray therapy (irradiation of deep-seated lesions) has been carried out with x-rays produced by 200 kv. This radiation is always filtered (combinations of copper and aluminum, or tin, copper and aluminum are usually used) and the distance of the target from the body surface has varied from 40 to 70 cm. During the past two decades machines of clinical utility operating at voltages above 200,000 have been developed. In many places 400 kv. equipment has replaced the 200 kv. apparatus for the treatment of lesions located deeply within the body, but more commonly 250 kv.

constant potential machines are being used for standard deep therapy. During the same time technical developments have made it possible to design, build and operate as clinical instruments machines in which the x-ray beam is generated by 1,000,000–2,000,000 volts (1–2 Mev). Considerable differences of opinion have been maintained regarding the advantages of these higher voltages over the 200 kv. x-ray beams, but the current tendency is strongly toward more universal use of 1–2 Mev machines (often termed supervoltage machines).

Besides irradiating the external surfaces of the body, it is possible by special cones to direct an x-ray beam into such cavities as the mouth and the vagina. Peroral irradiation, usually with a 200 kv. beam, introduces the radiation directly into an intraoral lesion without passing through a cutaneous surface. Some workers use pervaginal irradiation as a part of the radiation attack on carcinomas of the cervix uteri.

For clinical usage radium is specially packaged in a variety of ways. The radium salts are permanently sealed in metallic containers which may have the form of a needle, a tube or a cell. The kind of metal used varies, but platinum or gold alloys are the most common. As the name suggests, the needle is provided with an eyelet at one end and a sharp point at the other. After a thread or a wire is attached to the eyelet, the needle may be thrust into tissue, to be removed after a desired radium dose has been achieved. The cells may be introduced into sheaths of needle form and likewise used for interstitial irradiation. Either needles or cells can be placed in flat or tubular metallic containers and disposed at various desired points within such body cavities as the uterus, vagina, rectum or mouth; for this purpose permanent tubes may also be used. Any of these forms of packaging may be used in suitable arrangement for irradiation of surface lesions.

Radium has also been used, in a manner similar to the use of the x-ray beam, at a distance from a body surface. A large amount of radium, several grams, is housed in a thick-walled lead container which has a window on one surface through which the gamma radiation can emerge. The container is suitably set up by means of apparatus which permits adjustment of

distance from the desired body surface. Treatment with this arrangement is usually termed telecurietherapy (radium therapy at a distance) and was used more in the past than at present. It has two disadvantages: (1) the output of radiation is low and (2) because of the short distance in comparison with that of an x-ray machine, the proportion of radiation reaching a deep-seated lesion relative to the surface dose is less than with the x-ray apparatus. This is true despite the fact that the gamma radiation is more penetrating than 200 kv. x-rays and emphasizes the importance of the geometric factor of radiation distribution already mentioned. In contrast with the several grams of radium used in telecurietherapy, the radium content of needles, cells or tubes usually will range from 1 up to 50 mg.

In clinical radium therapy the gamma rays far exceed the alpha and beta particles in importance, and most radium treatment is gamma-ray therapy. Indeed, with few exceptions, radium sources are surrounded by sufficient thicknesses of metal to absorb all of the beta particles. Five-tenths millimeter of platinum, or its equivalent in other metals, accomplishes this purpose. The alpha particles are even less penetrating than the beta rays; several sheets of manuscript paper will absorb them. There is a sound reason for preventing the beta particles from reaching the tissue about the radium container. If beta rays do reach the tissue, they expend their energy within the first millimeter or two adjacent to the radium source and produce a sharp reaction in that zone. This then becomes the limiting factor in dosage. The gamma-ray dosage which is effective for a greater distance from the source—and adequate irradiation of this greater volume is the desired aim—must be restricted to prevent overdosage by beta rays near the radium container. Beta particles do have a limited use in the irradiation of some types of extremely superficial lesions. Recently even alpha irradiation has been employed clinically, but the procedure is still in the experimental stage.

The first disintegration product of radium is the gas radon. Radium salt can be kept in solution and the radon gas collected as it forms and sealed in metal containers which may then be used as sources of gamma rays. Since the half-life of radon is 3.824 days, the radioactivity of radon containers dies

out in about 30 days. Advantage is taken of this phenomenon in certain types of interstitial irradiation in which the small radon "seed" is implanted in tissue and allowed to remain there permanently.

With the advances of nuclear physics and the development of the uranium reactors, it has become possible to make a large number of elements radioactive. Of these a few have found applicability for therapeutic purposes. These are radioactive cobalt (Co^{60}), radioactive iodine (I^{131}), radioactive phosphorus (P^{32}), radioactive gold (Au^{198}) and radioactive strontium (Sr^{90}). The numbers refer to the atomic weights of the radioactive isotopes. The nuclear charge (atomic number) of each of these radioactive isotopes is the same as that of the stable element; the chemistry of the elements is not altered by the change in mass.

Co^{60} is produced by neutron bombardment of stable cobalt (Co^{59}) in metallic form in a uranium reactor. It has a half-life of 5.3 years and emits beta particles of 0.6 Mev maximum energy and gamma rays of 1.1 and 1.3 Mev. After these emissions the cobalt atom becomes nickel (Ni^{60}). In the form of metallic rods, adequately sheathed by suitable metallic tubing to absorb the beta particles and to prevent dissemination of cobalt oxide dust, Co^{60} may be used as a radium substitute. For such use it has the advantage of lower initial cost but the disadvantage of a much shorter half-life (5.3 compared to 1,590 years) requiring continual correction of dose output and frequent renewal. Co^{60} has entered clinical radiotherapy as a competitor of supervoltage x-ray apparatus. Radioactivity of 1,000–2,000 curies can be produced in cobalt occupying the volume of a 1 in. cube. The small size of this source makes an adequate approximation to the focal spot of a supervoltage x-ray machine, and from such a highly radioactive source the roentgen output at treatment distances is sufficiently high for clinical use. Contrary to the continuous spectrum of an x-ray machine, the gamma-ray beam from a cobalt source is essentially limited to the 1.1 and 1.3 Mev photons. Actually the Co^{60} beam seems equivalent in terms of depth dose to the beam of a 3 Mev x-ray machine.

I^{131} occurs as a fission product in reactor operation and is

prepared as NaI in basic Na_2SO_3 solution. It has a half-life of 8 days and emits beta particles of 0.6 Mev maximum energy and 2 gamma-ray photons 0.367 and 0.080 Mev, becoming stable Xe^{131}. The solution is usually administered by ingestion. In tracer quantities, it is used as a test of thyroid function. In therapeutic doses, it is used to treat some patients with hyperthyroidism and a limited number of thyroid cancers that have advanced beyond the scope of surgery and external irradiation.

P^{32} is produced by neutron bombardment of S^{32} in a reactor. It is prepared as a phosphate in weak HCl. It has a half-life of 14.3 days and is solely a beta ray emitter (maximum energy 1.7 Mev). Clinically it is used in the treatment of chronic granulocytic leukemia and polycythemia vera.

Au^{198} is produced by neutron bombardment of Au^{197} in a reactor. It is prepared as a colloid (particle size 0.003–0.007 microns), being produced in gelatin with ascorbic acid used as a reducing agent. Chiefly it has been used in the treatment of abdominal ascites and pleural effusions due to malignant neoplasms. In about half of properly selected cases, partial or complete control of fluid formation may be obtained for variable periods, thereby offering palliation.

Sr^{90} occurs as a fission product in reaction operation. It has a half-life of 19.9 years. Sealed in an appropriate applicator, it emits beta particles of maximum energy 0.54 Mev and its product Y^{90} beta particles of 2.27 Mev; no gamma rays are emitted. The end-product is $zirconium^{90}$. The applicator is largely used for ophthalmologic conditions involving the cornea and conjunctiva.

TISSUE EFFECTS OF RADIATION

Interaction with Matter

The basic physical effect which is responsible for the development of the tissue reactions that are produced and observed in clinical radiation therapy is ionization of tissue atoms. The removal of an orbital electron from an atom (ionization) alters the electronic configuration of that atom and thereby changes its chemical properties; this factor initiates the complex of

biophysical processes that eventually terminate in the clinical effects of irradiation. Interestingly enough it is an electron, conveniently termed an ionizing electron, which performs the work of ejecting an orbital electron from a tissue atom to create an ion pair. The ionizing electron in passing through tissue and coming into the vicinity of an orbital electron drives the latter away from its atom because of the force of repulsion which develops between these two bodies of like electrical charge. In doing this the ionizing electron gives up some of its energy; it may continue to create ions until its energy is completely dissipated.

Two questions concerning the ionizing electron are pertinent. Where does it come from? How does it acquire its energy? The answer to the first question is simple: the ionizing electron comes from any tissue atom. The answer to the second question is, in part, also simple: the energy comes from x-rays or gamma rays. But the explanation of the process of energy acquisition is somewhat involved.

So far, in discussing the nature of x-rays and gamma rays by speaking of their wavelengths, the implication has been made that these radiations are wave phenomena in the same sense as light or radio waves. This picture is correct; indeed, certain manifestations are most readily explained on a wave basis, but this is not the only conception that is valid. These radiations may be considered corpuscular—corpuscles not of matter but of energy. This conception portrays x-rays and gamma rays as discrete packets of energy to which the name photons is given. Being only energy the photon is weightless and chargeless. The high-energy photons correspond to the short wavelengths and the low-energy photons to the long wavelengths. The high-energy photons are able to penetrate more deeply into matter than those of low energy.

A beam of x-rays or of gamma rays may be visualized as a stream of photons, and the interaction of these radiations with matter is the interaction of photons with atoms. This is the source of the energy of the ionizing electron. In passing through matter (tissue in our case) photons encounter a varied experience. Some pass through unchanged; others are deflected (scattered)

by collisions with atoms and lose no energy in the process. However, many lose part or all of their energy. If a photon loses all of its energy, it is nonexistent, i.e., it has been completely absorbed.

Photons lose their energy through the medium of collisions with orbital electrons. It takes energy to free an electron from its atom, and part of the energy that a photon loses on collision is devoted to this purpose. The rest is acquired by the electron which now moves through the tissue as an ionizing electron and produces ions until its energy is gone. The photon produces an ion pair when it ejects an electron from an atom but, compared with the number of ions produced by the ionizing electrons, this type of ion production is slight. It is clear that x-rays and gamma rays produce ionization only indirectly. In the case of beta and alpha particles ion production is a direct process; these electrically charged particles themselves dissociate orbital electrons from their atoms just as the ionizing electron does.

The transference of energy from photons to orbital electrons takes place in two different ways. On collision the photon may give up all of its energy to the electron (photoelectric absorption with the production of a photoelectron). Or it may give up only a fraction of its energy to an electron and continue through the tissue in an altered direction as a result of the collision (Compton collision with the production of a recoil electron). Low-energy radiation (long wavelength) produces photoelectrons predominantly; high-energy radiation, on the other hand, creates recoil electrons rather than photoelectrons. A high-energy photon after producing a recoil electron may undergo further collisions and create more recoil electrons until either its energy is gone or it has passed completely through the tissue mass. After producing a recoil electron, the photon is deflected (scattered) by the collision and its new path may be in any direction, even backward, although most of the scattered photons will continue in a general forward movement. The probability of scattering backwards decreases with increasing photon energy.

MEASUREMENT. It is apparent that the interaction of photons and tissue atoms, while producing ionizing electrons,

creates a complicated situation. Some photons disappear by photoelectric absorption, some pass through unaltered, others are deflected from their initial paths without energy loss. Photons undergoing Compton collision may go off in any direction. The spatial distribution of the photons and of the points at which ionizing electrons are created becomes extremely complex. The picture is further complicated by the fact that, although the paths of the ionizing electrons are short (the ions are produced along these paths), they are very irregular. Nevertheless, it is essential to know something about the spatial distribution of the ions in the irradiated tissue mass, since the ionization is deemed responsible for the biologic effects.

For an x-ray beam this can be determined by measuring the number of ions produced at various points in an irradiated mass. Obviously such measurements cannot be carried out in a patient, so phantoms composed of materials which approximate the type of elements composing tissue are used. For a given set of conditions—voltage, filter, distance of the target from the surface of the phantom and surface area irradiated—the quantity of ionization at all points including the surface can be determined, and this distribution will be applicable whenever these conditions are reproduced. The results of such measurements usually are given in per cent of the amount found at the center of the irradiated surface; for example, for 200 kv., half-value layer 0.9 mm. Cu, target-surface distance 50 cm., surface area 100 sq. cm., at 5 cm. below the surface there is 60 per cent of the quantity of ionization present at the surface; at 10 cm., 30 per cent, and at 15 cm., 15 per cent. Tables and charts presenting such data for a variety of conditions have been prepared and are available in the literature. From these it is possible to determine with moderate accuracy the amounts of ionization, that is, the radiation dose, at various parts of the body under clinical conditions of irradiation.

The factors mentioned in the preceding paragraph—voltage and filtration, the distance of the target from the surface and the surface area irradiated—determine the distribution of the ions. Voltage and filtration by determining the quality of the beam determine the energies of the photons. The size of the surface field

irradiated is an index of the volume of matter irradiated; the volume irradiated is important because with increase in volume the contribution to ion formation by scattered photons increases. The target-surface distance affects the distribution purely in a geometric fashion, again related to the inverse square rule.

The higher the voltage and the filtration, the greater the proportion of ions found in the depths of the irradiated mass relative to the number at the surface. The larger the volume irradiated, the greater the depth dose. Likewise, relative to the surface dose, the depth dose increases with increased target-surface distance.

An additional point should be mentioned concerning ionization at the surface of the irradiated material. If one measures the number of ions produced at the surface of the phantom and then repeats the measurement at the same point in space after removing the phantom, the number of ions will be found to be less. Photons scattered backward from the depths of the phantom contribute ions to the surface; when the phantom is removed, no such contribution takes place and the number of ions is less. The backscatter contribution increases with the size of the irradiated field. This contribution decreases with beams of high photonic energy because high-energy photons tend to go forward, rather than backward, after collision with orbital electrons.

The present-day unit of radiation dose is based on ionization and represents an amount of x-rays or gamma rays that produces a certain number of ions in air under rigidly controlled conditions. This unit, the roentgen, is internationally accepted. The definition reads as follows:

"The roentgen shall be the quantity of x- or gamma radiation such that the associated corpuscular emission per 0.001293 gram of air, produces, in air, ions carrying 1 esu (electrostatic unit) of quantity of electricity of either sign."

This definition is more complex than may appear. Rewriting it, as follows, reveals more completely the conditions which must be met to arrive at the roentgen. The roentgen is that amount of x-rays or gamma rays which, on passing through 1 cc. of dry atmospheric air at 0 C. and 760 mm. of Hg pressure, causes the emission, from the atoms of this air, of electrons which, when

they give up all their energy in the production of ions in air, produce 2.095×10^9 ion pairs. Although indirect methods actually are used to obtain the desired quantities mentioned in the definition, the conditions can be met by means of an instrument called the standard free-air ionization chamber. Such instruments, however, are impracticable for clinical work and small secondary ionization chambers, known as thimble chambers, have been developed for this purpose. These chambers must be calibrated against a standard free-air ionization chamber.

The lower case letter r is the accepted symbol for the roentgen. It should be noted that r is not an abbreviation, therefore no period follows it. The use of a capital R is not only incorrect but confusing, since prior to the international agreement on the present definition of the roentgen there were several other definitions which used capital R as the symbol. Another error which is quite common is to speak or write of r-units or roentgen-units, e. g., a dose of 5,000 roentgen-units. Correct usage is 5,000 r or 5,000 roentgens. It is no more correct to speak of a dose of 5,000 roentgen-units than it is to state that a man is 6 foot-units high, weighs 150 pound-units and slept 8 hour-units the preceding night. To carry on with the use of words pertinent to therapeutic radiology, one may point out that *radiation* refers to x-rays, gamma rays, beta particles and alpha particles and *irradiation* is the process of exposing tissue or other matter to various radiations.

The roentgen deals only with ionization in air—nowhere in the definition does ionization in tissue appear. Even when measurement of ion production is carried out in a mass of tissue (or a phantom), the ions measured are actually produced in air, in the small volume of air present within the ionization chamber. As yet it is not possible to measure directly the ionization occurring in tissue. The number of ions produced in air is proportional to the number produced in tissue (the proportionality factor is essentially the ratio of the electronic densities) and thus the air ions can serve as a quantitative index of tissue dose.

The matter of radium dose has offered difficulties even greater than those encountered with x-ray dose. At one time the only way of stating radium dose was to give the product

of the weight of the radium and the duration of the exposure (milligram-hours) and to specify the type and thickness of the metal surrounding the radium source and the position of the latter in relation to the tissue treated. Radon presents a special situation. Its quantity is expressed in millicuries: 1 mc. is the amount of radon in equilibrium with 1 mg. of radium. The rapid decay rate of radon (half-life of 3.824 days) introduces a factor which is not present in the case of radium. One millicurie of radon left in place permanently is equivalent to 133 millicurie-hours (mc.-hr.).

Ionization measurement, useful in determining x-ray quantity, is almost useless in radium work because of the weak sources, the penetrating nature of gamma rays and the very short distance between the radium source and the treated tissue. Nevertheless, it has been possible to establish a relationship between gamma-ray quantity and the roentgen. The dose in roentgens at 1 cm. from a point source of 1 mg. of radium filtered by 0.5 mm. Pt is 8.26 r after one hour of exposure. Since it is possible to calculate the relative intensities at various points about a radium source, the dose in roentgens at these points can be found by using this relationship. When the dose for radium is expressed in roentgens, the latter are usually called gamma roentgens. This distinction is important because, although the number of ions produced is the same, the distribution of the ions in space with gamma radiation is different from that with x-rays.

Interaction of Radiation and Tissue

The tissue reactions produced and observed in clinical radiation therapy are the result of ionization of tissue atoms brought about by the ejection of orbital electrons. The altering of the electronic configuration of the atom changes its chemical properties and instigates biochemical and biophysical processes which lead to the phenomena noted clinically in irradiated tissues. Ionization takes place at the atomic or molecular level, but living protoplasm is much more complex than a simple aggregate of atoms or molecules.

"Living protoplasm is a complex material consisting of water, electrolytes, proteins and other organic compounds such as enzymes, carbohydrates, lipoids, hormones and growth agents. The cell therefore may be pictured as an exceedingly complicated system of physicochemical equilibriums (acid-base, oxidation-reduction, electrolytic dissociation, permeability, etc.) which shift in orderly ways under the influence of controlling factors (chromosomes, environment) to bring about the particular cell functions—secretion, contraction, conduction, support, proliferation, synthesis, differentiation, etc."[1]

With such complexity the normal state of living matter, it is not difficult to understand why the fundamental processes of the interaction of radiation and tissue are not known. Indeed, it is our lack of knowledge concerning what goes on in living protoplasm that stands in the way of determining how radiation disturbs it. Advance in insight of how radiation affects tissue will go hand in hand with increased understanding of the fundamental intracellular processes.

Only a limited amount of information is available regarding the reaction of protoplasm to irradiation and much of this is not completely substantiated. Many cellular processes such as respiration, glycolysis, nitrogenous metabolism and enzymatic activity have been studied, but little evidence has been found to indicate that they are significantly or permanently influenced even by large doses of radiation. Cellular pH has been studied with variable results and the effect of radiation on this factor cannot be considered established.

It has been demonstrated that proteins undergo denaturation when irradiated, but the application of this to living protoplasm has been criticized, since study of the colloid chemistry of protoplasm has shown that the living substance is unique in its behavior toward physical and chemical agents. Protoplasm is largely in a colloidal state and indications of colloidal change can be obtained by investigation of protoplasmic viscosity. Following irradiation there is first a decrease in viscosity—liquefaction—and then with increased exposure a sharp increase result-

(1) Henshaw, P. S.: Roentgen Rays and Gamma Rays: Biologic Effects; in Glasser, O.: *Medical Physics* (Chicago: Year Book Publishers, Inc., 1944), Vol. I, p. 1355.

ing in stiffening or coagulation. The coagulation is often manifested morphologically by the appearance of vacuoles in the cell. The permeability of the cell membrane, of obvious importance since it determines what goes in and out of the cell, has been studied in many ways and the evidence strongly suggests that radiation, from visible light to gamma rays, causes a substantial increase in permeability.

Considerable attention has been given to the morphologic changes in the nucleus of the cell after irradiation. These changes are striking and in stained microscopic preparations overshadow those of the cytoplasm. Following irradiation in adequate dosage, mitosis ceases; those cells in which the process has started tend to complete it but many cells die first. Resting as well as dividing cells are injured. The nuclei become large and hyperchromatic; chromatin tends to be clumped and the nucleoli prominent. After a time some mitotic activity appears but it is abnormal in character in many cells. Bizarre and giant nuclei may appear in considerable number. The nuclei may break up into small particles of chromatin, the nuclear membrane break down and the cell die. In such preparations vacuole formation in the cytoplasm may also be seen, along with changes in the Golgi apparatus and mitochondria; swelling of the cell may take place.

It is of interest and probably of fundamental importance that the changes seen in cells injured by radiation are not unique or specific. Other noxious agents, chemical, mechanical and others, produce the same picture of injury. This may mean that the same basic type of chemical or biophysical change is produced by any agent that is injurious to the cell. In the past the bizarre appearance of the cell nuclei following irradiation often has been interpreted as an indication, in the case of neoplasms, of increasing malignancy because of the similarity to marked tumor anaplasia; the true significance of this change, namely, injury or death, is now well known. Originally it was maintained that the nucleus was the sensitive part of the cell and that the cytoplasm was unaffected by the radiation. Now it is believed that the reaction of the cytoplasm is of some importance and that

the changes seen in the nucleus may in part be secondary to cytoplasmic damage.

Radiation injures the cell. If enough radiation is given, the cell will die. Up to a certain level of dosage the cell may recover, more or less, from the radiation damage; beyond this level the changes are irreversible and death follows. The question of whether radiation is ever stimulating has been much discussed with proponents for and against the affirmative. More than anything else the controversy has resulted from unclear concepts. Cells are harmed by radiation. In the reaction of cells, tissues and organs to the radiation injury, phenomena may take place which have the appearance of stimulation, proliferation or some other attribute of increased activity; many of these are reparative in character. The cell itself is always deleteriously affected. Clinically, advantage is taken of the reaction to the basic injury for a therapeutic purpose.

Another controversy has centered on the question of whether the action of radiation, particularly in the treatment of malignancies, is directly on the malignant cells or whether the radiation effect on surrounding tissues is responsible for tumor destruction. The evidence is clear that the primary and important effect is directly on the malignant cell. Certain effects on the "tumor bed," such as decreased vascularity and fibrous tissue proliferation, may contribute to decreased activity of residual neoplastic cells, but these in themselves will not suffice for tumor destruction. The "tumor bed," however, is of considerable importance from another point of view, that is, its ability to support an intense radiation reaction.

Radiosensitivity

An important concept in the application of radiation to living tissue for therapeutic purposes is radiosensitivity. The idea of sensitivity of tissue to the action of radiation may appear to be simple, with an obvious implication for clinical practice, that is, that radiosensitive tumors are suitable for irradiation and those of little sensitivity are not, or, that the former will be eradicated by the use of radiation whereas the latter will not. In reality

radiosensitivity embodies a complex of intricate components which are modified by various factors in the clinical picture. It is well worth while to explore the meaning of this significant concept.

One may begin with the following hypothetical experiment. Assume that we have a large population made up of one type of cell, essentially a pure culture. A large number of such cells

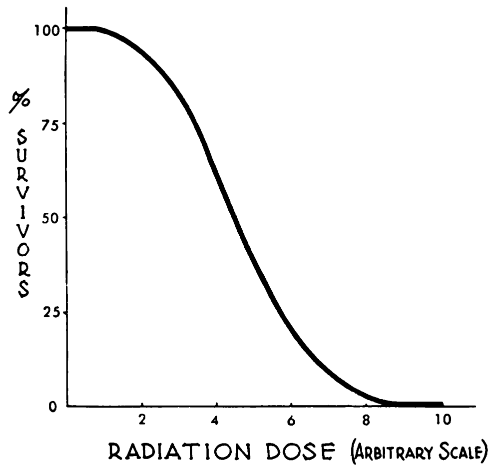


PLATE 82.—Biologic survival curve for homogeneous cell population, demonstrating variation in sensitivity of cells to radiation.

is given a certain dose of radiation. The effect of the radiation is studied after a suitable interval, and it is found that none of the cells died—100 per cent survived the radiation injury. A second large example is exposed to a greater dose and now, say, 10 per cent die and 90 per cent survive. As the dose is further increased with successive large samples, the percentage of survivors decreases until none survive. By plotting the dose against the percentage of survivors, a sigmoid (S-shaped) curve of the type shown in Plate 82 is obtained. This is a general type of biologic survival curve. First, one notes that a certain threshold value of dose must be reached before any cells die. Second, one notes the fact, particularly pertinent at the moment,

that the cells do not all die at the same level of dosage. Some are killed with a relatively small dose, but to kill all the cells a dose several times that of the minimal lethal dose may be required. In other words, the cells are not all equally radiosensitive. Even with a homogeneous population of cells variation in radiosensitivity is manifest. How can this be explained?

Precisely what causes this phenomenon is not known, but it is known that the basis is twofold. The first is essentially statistical and based on the discrete, discontinuous character (photons) of the radiation. Not every atom or molecule of the cell is ionized. The distribution of points of ionization is subject to the laws of probability. The situation may be described as follows (this is a crude description of the case and is not entirely correct): with smaller doses the chance of "vital" parts of a cell being sufficiently ionized to destroy it is less than with larger doses. The fact that not every particle in a field of radiation is subject to radiation effect is dramatized by the following quotation from Crowther:[2] "Suppose that it were possible to pass, through the air of an ionization chamber, x-radiation at an intensity of 1 r per second continuously, day and night, for 500 years, we should still leave about one third of the molecules unirradiated."

The second aspect is biologic and probably the more influential. No two cells, even though of the same type, are necessarily in the same biologic state at any given moment, and therefore may not react the same. An obvious difference is found between the cell in the process of division (mitosis) and the resting cell. Many experiments have shown that the dividing cell is more radiosensitive than the resting cell and even that at certain stages in the mitotic process it is more sensitive than at others. As early as 1904 Bergonie and Tribondeau, on the basis of effects produced in the testis, formulated the following statement: the biologic action of x-rays is greater the higher the reproductive activity of the cell, the longer the period of its mitosis and the less the degree of differentiation of the cell in respect to its morphology and function. If one views the cell

(2) As quoted in Warren, S.: Effects of radiation on normal tissues, Arch. Path. 34:443, August, 1942.

as in a state of crisis during mitosis, it becomes easier to comprehend in a general (but hardly a scientific) way why a cell should be more readily subject to radiation injury at that time. The changes in the state of the cell as it passes through resting and mitotically active phases may not be the only ones taking place. It is entirely possible that some aspects of metabolic activity may vary from time to time and that the cell is more susceptible in one phase than another; some suggestive but not conclusive evidence on this point has been reported.

It is seen that the background of radiosensitivity applied to

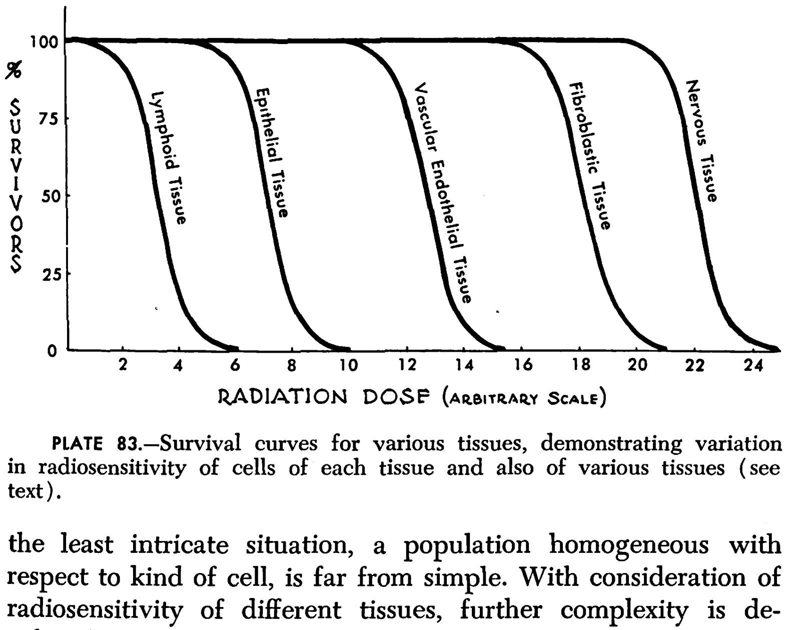


PLATE 83.—Survival curves for various tissues, demonstrating variation in radiosensitivity of cells of each tissue and also of various tissues (see text).

the least intricate situation, a population homogeneous with respect to kind of cell, is far from simple. With consideration of radiosensitivity of different tissues, further complexity is developed. If, for purposes of simplification, we assume each type of normal tissue in the human body to be composed of like cells, examination reveals that different tissues have different radiosensitivities. The following tissues are listed in order of decreasing sensitivity: lymphoid tissue, epithelial tissue, vascular endothelial tissue, fibroblastic and allied tissues and nerve tissue. We have seen that the cells composing each tissue vary in sensitivity, and now a second order of variation, that between

tissues, is imposed on the first. This concept may be pictured by using a survival curve to show the variation for the cells of a tissue and then placing the curve for each tissue in its appropriate range of radiation dosage (Plate 83: the features of this figure are purely arbitrary and only representational; no conclusion regarding absolute dose, relative dose, spread of each curve, etc., should be made on the basis of this figure).

Of course, the situation is more complex than depicted in Plate 83. The types of cells making up some of the tissues in the body may be quite diverse; epithelial tissue, for example, may differ in its cell type in different locations (skin versus mucous membrane) and even in one location may show differences (basal, prickle and squamous cells in skin). Thus each tissue probably should be represented by a family of curves rather than by a single one. Overlapping of the curves, or radiosensitivity ranges, occurs; for example, the dose which will kill some epithelial cells is probably the dose needed to destroy the more resistant lymphoid cells. It should be stressed that the different sensitivities of different tissues are not due to inequalities in amount of ionization taking place in these tissues; the same kind of atoms make up the various tissues, therefore with the same dose the same number of ions are produced.

Our primary interest in radiosensitivity relates to its application in the treatment of malignant neoplasms, and analysis here reveals the compounding of complexity. Tumors exhibit different orders of radiosensitivity. A tumor of Hodgkin's disease or a lymphosarcoma regresses with relatively small doses of radiation, whereas melanoblastomas, certain gliomas and many bone tumors may not respond to the largest doses that can be given to the involved part of the body.

If we could determine the sensitivity of the individual cells making up one tumor, we would find that variation existed just as in our hypothetical example of a population of like cells. If we were to study a large number of tumors of the same type, we would find sensitivity variation in the form of a sigmoid survival curve. This has been done experimentally in animals with transplantable tumors, and clinical instances of such variations are encountered. The situation for neoplasms would be

depicted in Plate 83 if we replaced the labels for the tissue types with names of certain tumors, for example, lymphosarcoma instead of lymphoid tissue and melanoblastoma instead of nerve tissue.

The "law" formulated by Bergonie and Tribondeau states that the biologic action of radiation is greater the less the degree of differentiation of the cell in respect to its morphology and function. Applied to neoplasms, this means that the more anaplastic (the more de-differentiated) a tumor is, the greater will be its radiosensitivity. This has been carried over into the clinical treatment of neoplasia but its role as an indicator of the tumors that should be treated with radiation has frequently been overemphasized. Sometimes the mere fact that a lesion was poorly differentiated has been considered sufficient evidence of radiosensitivity and irradiation carried out (conversely, because a tumor was well differentiated, radiation treatment was considered contraindicated). It should suffice to point out that a poorly differentiated melanoblastoma may be, in accordance with Bergonie and Tribondeau's statement, more sensitive than a well-differentiated one; on the survival curve of all melanoblastomas, the undifferentiated lesion will die off in the lower dosage part of the curve. But all the melanoblastomas will require a high dose for destruction and are relatively highly resistant. Within one tumor type a poorly differentiated specimen may be more sensitive than a well-differentiated one, but a poorly differentiated chondrosarcoma may be many times more resistant than a well-differentiated lymphosarcoma.

At times a high degree of anaplasia in a neoplasm may be decisive in determining that irradiation rather than surgery be the method of treatment, but this may be on grounds that have nothing to do with radiosensitivity. The manifestations of malignancy are usually more vigorous in anaplastic neoplasms; they grow more rapidly, infiltrate more readily and more extensively and metastasize sooner than well-differentiated tumors. Thus the probability of metastasis may be so high or the likelihood of wide local infiltration so evident that radical surgical resection of the primary site may be inadvisable. Then, if the lesion is of a type that may be radioresponsive, often the decision to irradi-

ate is made, a decision based not on radiosensitivity because of anaplasia but on the growth characteristics of the anaplastic lesion.

In a general way the radiosensitivity of neoplasms tends to follow that of the tissue from which the tumor is derived. The tumors arising from lymphoid tissue are among the most sensitive to the action of radiation. Tumors arising from bone or nerve tissue are among the most resistant lesions. Exceptions exist to this general tendency; for example, one of the gliomas, the medulloblastoma, is relatively sensitive.

The character of the tissues in which neoplasms are growing may be of considerable importance for clinical radiotherapy. Among the factors considered important in the tumor bed are its vascularity and the character of the connective tissue. There is evidence that radiosensitivity decreases with poor circulation. Carcinomas arising in burn scars do poorly under radiation therapy; the impoverished circulation of the scar may account for this. Certainly tumor beds of poor vascularity do not tolerate intense radiation reactions and, although the neoplasm may be destroyed, the tissues may never recover from the radiation reaction.

At this stage in the discussion it should be evident that radiosensitivity is not an absolute but a relative phenomenon. No mention has been made of the inability of radiation to destroy a tissue or a neoplasm for the very good reason that any tissue or tumor can be destroyed. The quantity of radiation for this purpose will vary; it will be small in some instances and enormous in others. In the body the magnitude of dose is limited by the tolerance of the normal tissues included in the irradiated volume, and tumors which are not eradicated with the maximal dose have been called radioresistant. Tumors which disappear with the maximal or less than maximal dose have been termed radiosensitive, with the degree of sensitivity corresponding inversely to the magnitude of the requisite dose. Such a concept of radiosensitivity is a changing one because, as therapeutic radiology develops, more neoplasms are brought into the class of radiocurable tumors either by altering the method of administering the maximal radiation dose or by developing ways of

increasing the size of the tolerated dose. Another definition of radiosensitivity states that tumors regressing with small doses are radiosensitive whereas those requiring large doses are radioresistant. This definition provides us with the paradox of curing, by radiation methods, radioresistant lesions.

These difficulties of clinical definition arise because of the relative nature of radiosensitivity on one hand and, on the other, the attempt to correlate radiosensitivity with radiocurability. These two concepts do not go hand in hand. The lymphoblastomatous tumors, such as Hodgkin's disease, are among the most sensitive encountered but are incurable. Cornifying squamous cell carcinoma of the lip or skin relative to Hodgkin's disease is radioresistant, and yet the ability to eradicate these tumors by radiation methods is high.

Radiocurability

More profitable than trying to force the broad concept of radiosensitivity into a rigid clinical definition free of paradoxes is consideration of the factors contributing to radiocurability. These are (1) tumor type, (2) anatomic extent, (3) site, (4) character of the tumor bed and (5) relative sensitivity to radiation. For successful eradication a certain favorable relationship must exist among all of these factors; it takes only one to destroy this relationship with consequent failure to cure. Some notion of the interweaving of these factors may be acquired from the following statements in which the factors are indicated in brackets after the part of the discussion pertinent to each.

Carcinoma of the lip (tumor type) requires large doses (relative sensitivity) which can readily be given to this surface lesion (site) and is tolerated with ease by the lip (tumor bed); many carcinomas of the lip are not excessive in size and usually tend to metastasize late (anatomic extent); the rate of cure in these lesions is high. The masses of Hodgkin's disease (tumor type) regress with small doses (relative sensitivity), but lymph nodes in many parts of the body become involved (anatomic extent); it is not possible to eradicate the disease at every site

involved, and cure cannot be obtained. Carcinoma of the oral part of the tongue (tumor type; site), if it has not infiltrated too widely nor metastasized (anatomic extent), may be destroyed even though the neoplasm may be well differentiated and require high doses (relative sensitivity); the accessibility of the tongue permits the delivery of high radiation doses (site); the tongue will recover from the intense radiation reaction (tumor bed), perhaps with some scarring and sometimes with several subsequent episodes of soft tissue necrosis (tumor bed). Fibrosarcoma of the soft tissues (tumor type) rarely regresses even with large doses (relative sensitivity). Carcinoma of the skin (tumor type) requires fairly large doses (relative sensitivity) which are readily introduced into this superficial lesion (site), but when it occurs in an old burn scar (tumor bed) the results of irradiation are poor because of difficulty in recovery from the radiation reaction. The squamous cell carcinoma of the esophagus (tumor type) is probably no more resistant to radiation (relative sensitivity) than the cornifying squamous cell carcinoma of the skin but, because of the deep-seated location of the lesion (site), it is difficult to introduce an adequate dose and, if introduced, the region will not tolerate it as well as subcutaneous tissue does (tumor bed).

Selective Effect

Underlying the successful employment of radiation in the treatment of malignant neoplasms is the achievement of a selective effect on the tumor. Any neoplasm arising in the body can be destroyed, but this does not mean that clinical cure can always be obtained. The limiting factor is the necessity for preservation or relative preservation of the normal tissues and organs included in the irradiated volume. In the ideal situation the tumor will be completely eradicated and the normal tissues will show no evidence of damage either structurally or functionally. In practice this ideal is not always attained and one accepts, as a compromise, a certain degree of permanent residual damage as a sequel to the destroying of the lethal tumor. The extent of permissible alteration of normal structures varies in

different situations. Obviously the postirradiation changes must be compatible with life and with a state of relative symptomatic comfort. Radiation treatment has achieved its present measure of success in the field of malignant neoplasms because under varying conditions and with diverse technics a selective effect is possible. This is the basis of radiation therapy.

The selective or differential action of radiation results from the fact that some neoplasms are more sensitive to radiation injury than are the normal structures in the irradiated volume. Not the radiosensitivity of the neoplasm itself but the difference in the radiosensitivities of the neoplastic and normal tissues is the important factor. Obviously, if the normal structures are damaged to a greater extent than the neoplasm, irradiation can be of little benefit unless these structures can be sacrificed—a situation rarely encountered in clinical practice. If the normal elements are not at all or are little damaged, while the neoplasm succumbs, a successful result may be obtained if other factors are favorable.

Frequently in discussions of the differential action of radiation only the difference in the sensitivities of the neoplasm and the skin is considered. The skin has been and still is important in this connection, but with the use of more and more penetrating radiations the skin is becoming less often, and other tissues more often, the limiting factor. The effect of radiation on intestinal mucosa, deep-seated blood vessels and connective tissues, lung parenchyma and so on, rather than on the skin, may determine the amount of radiation that can be given. It is evident that in any significant volume there will be more than one kind of normal tissue present. We have already seen that there is considerable variation in the sensitivity of different normal tissues, and therefore we are concerned with the difference between the sensitivity of the neoplasm and the sensitivity of each of the normal components. The margin of difference in radiosensitivity of the tumor and normal tissue is determined not necessarily by the most sensitive tissue but by the most sensitive tissue that is essential to the maintenance of the integrity or function of the irradiated region. Lymphoid tissue, present in many parts of the body, is destroyed more readily than

are most neoplasms, but since the loss of this tissue in a limited region is not of vital importance, the unfavorable relationship of the sensitivity of a neoplasm and of this tissue is not significant.

The cell as a living unit is capable of resisting injury induced by external agents and, if the damage is not too great, it may recover. The phenomenon of recovery can be demonstrated in skin by giving at a single sitting a dose which produces a slight erythema and by reproducing this reaction by giving two equal fractions separated by an interval of 24 hours. With the fractional administration, the total dose given exceeds the single dose and the difference is an index of the extent to which the cells of the skin had recovered, during the 24 hour interval, from the radiation effect. Just as radiosensitivity may vary among different types of cells, so may the power of recovery. Differences in the rates of recovery of cells contribute to the differential action of radiation when a fractional technic of administration is employed. In such a technic a fraction of the total radiation dose is given at regular intervals, usually daily. If the neoplastic cells recover less rapidly than the normal ones, then with each succeeding fraction the summated radiation effect becomes greater in the neoplasm than in the normal tissues. The accumulated radiation injury in the tumor cell may become so great that the cell dies; the normal cell, with a lesser accumulation of radiation damage because of its faster rate of recovery, may survive.

A favorable difference in the radiosensitivities plus a favorable difference in the rates of recovery of neoplastic and normal cells will result in a good selective effect. Theoretically, provided an adequate difference in recovery rates exists, the radiosensitivities of the two types of cells may be the same and a good selective effect still obtained. Quantitative determinations of recovery rate have been made only for skin. For other normal tissues and for tumors, although these rates have not been determined, clinical observations have suggested that differential recovery rates exist.

Another factor which enters the picture of any selective effect obtainable by irradiation is the ability of the irradiated normal tissues to repair or to regenerate and thus to compensate

for any destruction that may have taken place. Repair and regeneration are not to be confused with recovery. Recovery, in the sense we have used the term, refers to the return of a cell to its initial state following radiation injury. Regeneration means reproduction of surviving cells to replace destroyed cells, while repair may be thought of as replacement of a destroyed tissue by a different one (usually fibrous tissue). If one remembers that the cells of any normal tissue may have a fairly wide range of radiosensitivity, it becomes evident that complete escape of any normal tissue from some cellular destruction is unlikely. The minimal residual damage, that is, the maximal selective effect, is demonstrated by those tissues having the greatest powers of repair and regeneration.

The various technics of administration of radiation in use today depend for their selective effect on a combination of three factors: (1) difference in radiosensitivities of neoplastic and normal tissues, (2) difference in recovery rates of neoplastic and normal cells and (3) ability of normal tissues to regenerate and repair. In different technics the contribution of each to the final result may be different. In technics involving fractionation of the total radiation dose the first and second factors are of primary importance. In technics of minimal or no fractionation, such as massive dose technics, the second factor is not operative and a final successful selective effect is brought about by a combination of the first and third factors, with the latter usually contributing less than the former.

When the irradiated zone tends to approximate fairly closely the zone of neoplastic involvement (radium or radon sources implanted in the tumor, irradiation of small skin carcinomas, peroral irradiation, etc.) the volume of normal tissue is small. With deep-seated lesions treated by external irradiation, considerable masses of normal tissue may be traversed by the radiation before the tumor is reached. Of necessity these tissues must be heavily irradiated to achieve an adequate tumor dose. It may be impossible to obtain the requisite dose in the tumor without grossly overdosing the overlying tissues. Such a situation would take precedence over the factors leading to a satisfactory differential action and failure would follow. To minimize

the amount of radiation delivered to overlying normal tissues, "cross-fire" technics are used which concentrate the dose in the region of the tumor and, by alternating between a number of surface fields on the body, distribute the normal tissue dosage among several zones. All factors may be favorable for achieving a selective effect but cure not obtained because of the occurrence of metastases outside the treated region. Like surgery, radiation treatment is a local form of therapy in that all the neoplastic cells must be adequately irradiated (just as with surgery all must be excised) to achieve cure. If the size of the lesion is misjudged or if the anatomic situation makes it impossible to give an adequate dose to all the cells, recurrence will develop no matter how favorable the differential action. The particular clinical circumstances of a patient are capable of wiping out the effect of even the best possible relationship of the factors leading to selective action.

Malignant diseases do not constitute the only field of application of radiation as a therapeutic agent. A considerable variety of inflammatory and infectious processes may be cured or benefited by irradiation. In most of these the quantity of radiation employed is small, usually only a fraction of the amount necessary to produce erythema of the skin. The mechanism of radiation action in these conditions is poorly understood. In the case of bacterial infections it is known that the mechanism is not radiation death of the causative organisms for, although bacteria can be killed by radiation, enormous doses are required, doses which cannot be tolerated in vivo. A number of hypotheses have been advanced but none, as yet, is adequate. The broad principle that seems to apply is that reparative tissue reactions to the cellular injury produced by the small dose are responsible for the favorable results. Thus viewed, concepts of radiosensitivity and differential action are hardly applicable to this field.

Time Factor

The importance of the technic of fractionation of the total radiation dose in the treatment of neoplasms has been pointed

out in the discussion of selective effect. This technical expedient takes advantage of differences in recovery rates and represents one aspect of a broader factor which is deemed significant in radiation therapy. The magnitude of the radiation dose is not the only important variable; of equal significance is the distribution of the dose with respect to time—the time factor. A dose of 660 r of a certain quality of radiation applied to the skin will produce a slight erythema; two doses of 330 r given with an interval of 24 hours will not cause an erythema, even though the absolute size of the total dose is the same in the two instances. A certain amount of recovery from radiation effect takes place during the time between the two doses and the net biologic effect becomes less. The rate at which the total radiation dose is introduced must therefore be specified to denote complete knowledge of the resultant biologic effect of that dose.

Obviously the time factor of dosage can be varied greatly: treatments can be given daily, every other day, weekly and so on. The quantity given at each treatment can be varied. Too small a fraction may fail to build up an adequate cumulative effect. Too large a fraction may also be disadvantageous. Not only may the method of fractionation vary but also the rate at which each fraction is administered. A dose could be given at the rate of 5 r per minute or at 50 r. Although it is known that divided dose procedures are usually the best for many tumors, no complete agreement exists regarding the rate at which a fraction should be given, the size of the fraction and the intervals between the fractions. Many small skin carcinomas have been adequately treated with one or two massive doses. With intracavitary or interstitial radium treatment, a small weight of radium may be used for a long time or a large weight for a short time—the same number of milligram-hours or gamma roentgens for both—but with the prolonged exposure the biologic reaction will be less vigorous.

The time factor, besides introducing recovery rate as an important determinant of the ultimate biologic effect, may bring other factors into play. It has been thought that changes in

radiosensitivity may occur in normal and neoplastic tissues within the cycle of injury and recovery which takes place during irradiation. Clinical attempts have been made to identify the periods of increased sensitivity of the neoplasm and to concentrate the radiation dose at these times. There is little exact information regarding the phenomenon of periodicity of tumor sensitivity but it is of interest because it demonstrates a path which, if developed, may lead to greater efficiency of radiation within the dosage limits which now prevail. Evidence that may be a clue to future changes in the time factor is found in the fact that diurnal periodicity of mitotic activity has been demonstrated in the epidermis of albino rats, the rate being higher during the day than at night, whereas mitotic activity of epidermoid carcinoma of this animal is constant throughout the 24 hours. If radiosensitivity is greatest during mitosis, radiation should be given when the mitotic activity of the skin (normal tissue) is least to obtain an increased differential effect.

Effects of Radiation on Normal Tissues

The changes produced by radiation in normal tissues and organs have been extensively studied both clinically and in animal experiments. The publications on this subject are many and detailed but here only a brief review is given, largely from the point of view of those changes taking place in man during the course of therapeutic irradiation.

SKIN AND APPENDAGES; MUCOUS MEMBRANE. Radiation effects on the skin have held the interest ever since the beginning of radiology. The first skin reactions, accidentally induced during the early work with x-rays and radium, centered attention on the biologic action of these radiations and opened the door to the development of therapeutic radiology. The cutaneous erythema has been valuable as a dosage guide; the severe changes produced in skin by improper irradiation have served as a warning, too often of tragic significance, of the dangers inherent in unskilled use of these agents.

When radiation is administered to the skin, no sensation is

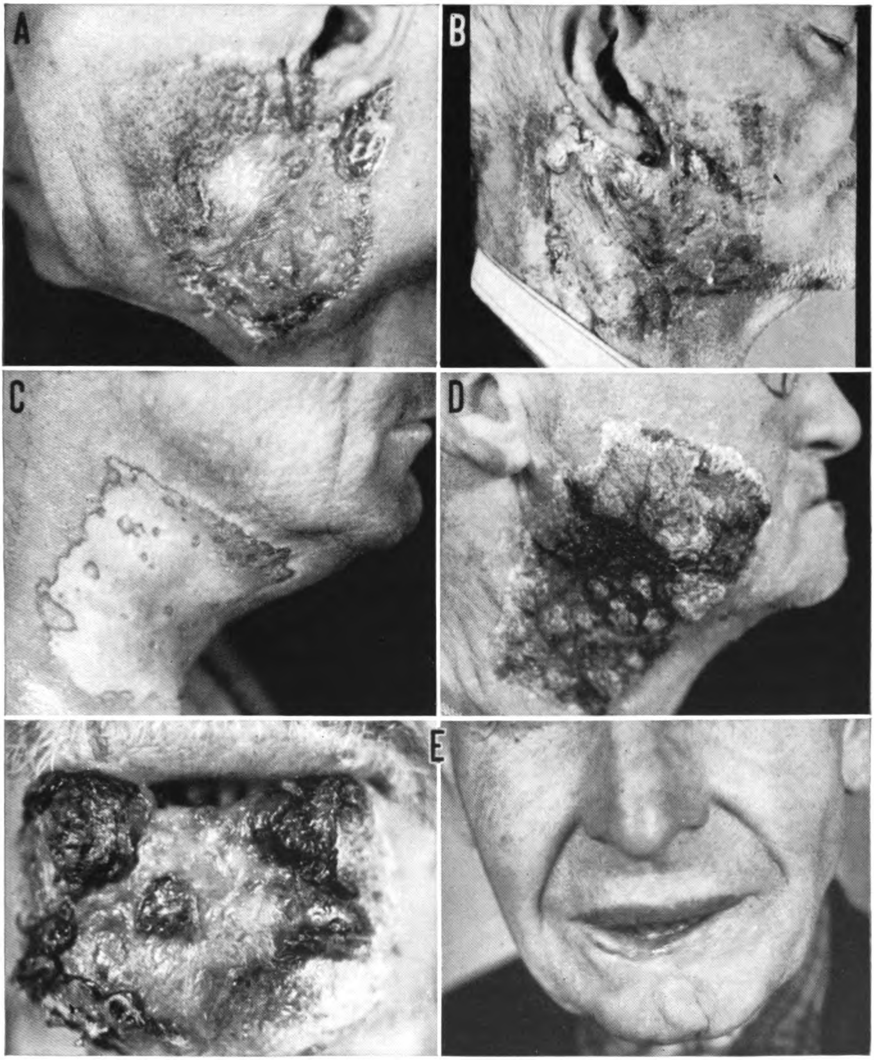


PLATE 84.—Radiation reaction in skin. *A–E,* sharp reactions caused by fractional high-voltage external irradiation to high total doses. Desquamation and exudative reaction with crusting are seen. *C,* re-epithelization at margins of denuded area and from residual islands of epithelium within area. *E, right,* appearance of skin after healing of reaction, *left.* All reactions healed completely.

experienced by the patient and on completion of the exposure the skin is unchanged in appearance. In some patients a transient flush (erythema) develops after several hours and then disappears, leaving the skin as before irradiation. After about 10 days an erythema develops. These reactions appear only with doses exceeding a certain threshold value. The second or main erythema is the important one: its intensity depends on the quantity of radiation applied and it usually lasts for about four weeks, fading gradually. About three weeks after irradiation, pigmentation of the skin begins to appear and may disappear in a few months but may persist permanently. This is the cycle seen when a single dose is given.

In the treatment of malignant tumors more often radiation is applied daily and carried to the point of sharp intense reactions which, nevertheless, are reversible and will heal with remarkably little residual skin damage. As treatment is carried on, the erythema deepens, vesication occurs, the vesicles rupture and the superficial layers of the skin are shed. The exposed deeper layers are bright pink and ooze yellowish serum. Gradually most of the irradiated field becomes denuded of epithelium. Treatment is usually discontinued at or before this stage. Healing begins shortly afterward and may require several weeks, depending on the intensity of the reaction and the size of the denuded area. The skin reaction may be of lesser degree and show dry scaling rather than the moist reaction associated with epithelial denudation. Owing to moisture and friction in areas such as the groin, axilla and vulva, skin reactions may appear early and be more severe than in dry regions. Because some degree of variation exists in the reaction of the skin it must be closely observed; determination of the limits of tolerance of the skin is a matter of judgment, not of formula.

Excessive irradiation either by single large doses or by multiple, repeated small doses will result in permanent progressive damage of the skin associated with repeated or chronic ulceration that resists repair (the so-called "x-ray or radium burn"). The acute phase of the reactions brought about intentionally in the treatment of malignancy, even though fairly severe in-

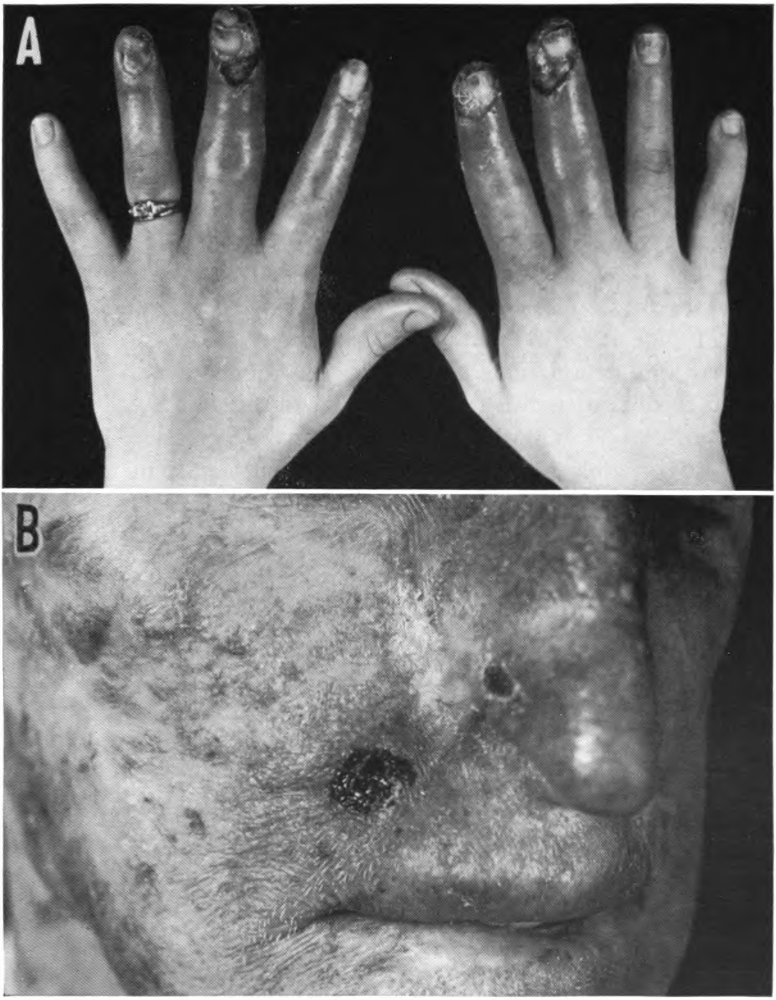


PLATE 85.—Radiation damage of skin. *A*, gross x-ray overdosage of fingers during treatment of dermatitis. Note edema of fingers, erythema (shown by darkening of skin) and multiple ulcerations. This was the condition when patient was first seen. Later the finger-nails and distal bony phalanges in ulcerated areas sloughed off. *B*, chronic radiation dermatitis due to repeated treatment with small doses of x-ray for dermatitis. Multiple carcinomas of facial skin developed. Apparent ulcerations on nose and face are sites of cautery destruction of carcinomas.

flammatory processes, is distinguished from the chronic nonhealing reactions by a capacity for complete repair. Skin which has passed through such a reaction will rarely tolerate a second experience of this type. As is well known, carcinoma may develop from the chronic ulceration of excessively irradiated skin.

Irradiated skin may exhibit minimal to marked degrees of atrophy and telangiectasis. The extent of the changes is determined largely by the factors of dosage. Epilation follows doses which are smaller than those necessary to produce erythema and with these doses will be temporary. With larger doses the loss of hair may be permanent; however, this does not find clinical application since permanent skin damage must be produced to obtain such a result. The sebaceous and sweat glands are sensitive to radiation, and functional depression achieved with smaller doses is utilized by the dermatologist in the treatment of some skin disorders. With large doses, such as those used in the treatment of malignancy, permanent abolition of function occurs and dryness of the skin persists.

The mucosal reactions commonly seen are those of the mouth, pharynx and vagina. The stratified squamous cell epithelium of these mucous membranes tends to be more sensitive than the skin and the radiation changes develop sooner and with smaller doses. Reddening and slight edema of the mucosa are followed by desquamation of the superficial layers of the epithelium and then by the formation of a membrane. The membrane is somewhat similar to a diphtheritic membrane, varies from white to yellow in color and consists of a fibrinous exudate. Healing usually occurs more rapidly than in the case of the skin reactions. In the mouth the mucosal reaction is accompanied by loss of taste which may be very slow in returning.

BLOOD VESSELS. The effect of radiation on blood vessels is important. Like other tissues, these structures are injured. With moderate doses the injury is mild and recovery takes place. With large or excessive doses the changes may be severe, permanent and progressive and may lead to serious complications. The endothelial lining is the most sensitive of the various coats, its sensitivity approximating that of the skin. The damage

tends to be more severe in the small vessels and capillaries than in the large vessels. Shedding of the endothelial lining, atrophy of the muscular coat and fibrosis of the adventitia lead to progressive narrowing of the lumen and thickening of the vessel wall. The end-result is obliterative endarteritis with impoverishment of circulation.

BLOOD AND BLOOD-FORMING TISSUES; SPLEEN; LYMPHOID TISSUE; BONE MARROW. Ordinary therapeutic radiation exposures rarely cause dangerous or permanent changes in the blood. Decrease in the number of cells of all types in circulating blood can be brought about if sufficient radiation is administered. Severe damage of the cells of the blood-forming organs may also be produced. The larger the dose the more profound the damage and the slower the recovery. Severe damage may cause death from anemia, agranulocytosis or purpura.

Of the peripheral blood cells the lymphocytes are the most sensitive, the polymorphonuclear leukocytes the next, and the erythrocytes, the least. Leukopenia due primarily to decrease in the number of lymphocytes is not uncommon. The hemopoietic tissues exhibit relative sensitivities that correspond to the cells they produce. The lymphoid organs are highly susceptible to radiation damage. The lymphocytes in the spleen, lymph nodes and thymus show rapid changes after irradiation, and destruction may be considerable. The bone marrow is more resistant than lymphoid tissue, with the erythropoietic tissue less affected than granulopoietic tissue by equal dosage. Although the initial resistance of the red cell-forming tissue is considerable, once damaged its ability to recover is limited; the regenerative ability of the granular elements is much greater. The end-result of irradiation of the bone marrow, depending on dosage, may be a gradual return to normal, partial repair producing a hypoplastic marrow or progressive injury going on to aplasia and death.

Death due to aplasia of the bone marrow is rarely if ever seen with therapeutic doses. Accidental overexposures of large parts of the body, either acute or chronic, account for the aplasias seen in the human being. They may occur in those who work with radiation without adequate protection.

GONADS; EMBRYO; GERM PLASM. That sterility in both the male and the female could be produced by irradiation was discovered early (1903). In the testis the spermatogonia can be destroyed with moderate doses, but adult sperm are very resistant. Following irradiation spermatogenesis ceases because of the effect on the spermatogonia. Aspermatogenesis is only temporary with small doses (200–300 r in the testis); regeneration of surviving spermatogonia repopulates the seminiferous tubules and sperm formation is resumed. With larger doses (about 600 r) the spermatogonia disappear completely and sterility is permanent. The Sertoli cells are considerably more resistant than spermatogonia and are not affected by doses producing temporary sterility; no change in libido or potency is noted. Even with doses which destroy all the spermatogonia, the Sertoli cells may survive, although deficiency symptoms such as those following surgical removal of the testes have been reported.

In the ovary the ova and the epithelium of the graafian follicles are the sensitive parts; the more mature the follicle the more vulnerable it is to radiation. Temporary or permanent sterilization may be produced depending on the size of the dose. A dose at the ovary of less than 200 r usually results in temporary cessation of menses whereas doses of 300–600 r cause permanent castration. Complete castration is readily brought about in women near the normal menopause but this may prove difficult in young females. In complete sterilization all the follicles are destroyed and the ovary becomes functionless and atrophic; the result is total castration. Smaller doses permit survival of the least developed oocytes and after a period follicles will form and menstruation be re-established.

There is general agreement that moderate to heavy irradiation deleteriously affects the embryo in utero. Death of the embryo resulting in abortion commonly occurs. Even in the later stages of pregnancy, when death is less likely to occur, the fetus may be seriously injured and exhibit malformations at birth.

Radiation affects germ plasm by producing mutations; this

attribute has been used extensively in experimentation in botanical and zoologic fields. The mutations arising after irradiation are of the same type as the spontaneous variety—irradiation increases the rate of occurrence. The mutations are usually recessive and, if not lethal to the embryo, may not become manifest for several generations. Complete agreement as to whether these facts apply to man has not been reached, but many maintain that irradiation of the gonads which will not lead to permanent sterilization should be avoided because of the risk of genetic alteration.

GLANDULAR STRUCTURES. The function of the salivary glands is readily depressed by irradiation. This finds clinical application in the treatment of salivary gland fistulas. Dryness of the mouth is a common sequel of heavy irradiation for intraoral and pharyngeal neoplasms and may persist for many months. The pancreas is generally considered to be resistant to radiation injury and no reports have been given of damage in man. There is no evidence that with therapeutic doses pancreatic secretion can be suppressed, as in the case of the salivary glands. The liver is classed as a relatively resistant organ; the regenerative ability of liver cells is high and leads to rapid recovery from radiation effects. Undoubtedly excessively high doses may produce hepatic necrosis. The normal thyroid gland can withstand high radiation doses without evidence of damage and this also appears to be true for the pituitary gland. It is rare to find convincing evidence of injury of adrenal glands after therapeutic irradiation: histologic studies in animals suggest that the medulla is highly resistant whereas the cortex exhibits some degree of sensitivity.

MISCELLANEOUS ORGANS. Changes are produced in the lung by high or often repeated, moderate doses. The endstage of the radiation inflammatory reaction is pulmonary fibrosis. Such changes are demonstrable radiographically and may be seen after heavy irradiation for carcinoma of the breast, pulmonary or mediastinal tumors. During the acute pneumonitis there may be cough, dyspnea and sometimes fever but often the patient is asymptomatic. The contracting fibrous tissue causes deviation

of mediastinal structures. The kidney, although showing some vulnerability to radiation, cannot be classed as radiosensitive. With high doses, such as those used in the treatment of renal tumors, histologic evidence of damage has been described; experimentally, nephritis has been produced by heavy irradiation of exposed kidneys. The epithelium of the urinary bladder can tolerate rather high radiation doses and it is frequently called on to do so since the bladder inevitably receives a considerable share of the high x-ray and radium doses given for carcinomas of the cervix; in a small number of patients late ulceration of the vesical mucosa occurs. Interest in the eye centers chiefly on the reports of development of lens cataract after vigorous irradiation. Peripheral and autonomic nerves are highly resistant. The nerve elements of central nervous system tissue also appear to be little affected by ordinary therapeutic irradiation, but damage of the brain and spinal cord can occur with high doses because of injury to blood vessels. With moderately large doses gastric secretion may be inhibited temporarily. The reaction of the intestine is inflammatory, and damage in the form of ulceration and stenosis may be produced under certain clinical conditions of irradiation. Radiation affects the intestinal mucosa directly, but secondary factors such as mechanical trauma, infection and damage of the vasculoconnective tissue play a part.

BONE AND CARTILAGE. The reactions of bone and cartilage are of interest and of clinical importance. Normal adult bone is capable of withstanding high doses of radiation without any apparent macroscopic alteration, but this does not mean that it is unaffected. Impairment of vitality takes place in proportion to the magnitude of the radiation dose. This becomes manifest when the irradiated bone is exposed to trauma or infection; in its impaired state it may be unable to tolerate such additional insult and develop necrosis. Protected bone only rarely shows necrosis and sequestration.

Necrosis of the mandible is not uncommon when intraoral carcinomas are irradiated. If the mandible is invaded by neoplasm, necrosis is almost inevitable. It may occur even years after treatment, following trauma and infection incident to dental

extractions. Sequestration takes place slowly and the process of necrosis, separation of the dead bone, removal of the sequestrum and healing may take one to two years; this is a painful and distressing complication. Adult cartilage, like bone, tolerates large amounts of radiation as long as it is free from neoplastic invasion and is not subject to infection or trauma.

Irradiation of epiphyseal cartilage causes a decrease in its rate of growth which will lead to shortening of the affected bone. Moderate doses at an epiphysis in infants or children may produce this effect.

Radiation Sickness

Some patients react to treatment by developing "radiation sickness." The symptoms come on some hours after exposure and consist of varying degrees of malaise, nausea, anorexia and vomiting. Such symptoms are not an invariable accompaniment of radiation treatment but are quite distressing in an occasional individual. Irradiation of the abdomen, especially the upper half, most commonly produces these symptoms, but they may also follow treatment of other parts of the body. Rapid disintegration of tumor tissue with protein absorption and radiation effect on liver and on gastrointestinal mucosa have been thought to be causative, but the basic factors are not known. In some patients the symptoms are obviously on a psychogenic basis, the result of being told by patients or friends that irradiation always produces radiation sickness. There is no certain means of avoiding or abolishing the symptoms, but suitable adjustment of the daily radiation dose will minimize their occurrence. Of the numerous remedies used, the most popular is administration of various members of the vitamin B complex.

10

Skin, Lips and Oral Cavity

CARCINOMA OF THE SKIN

CARCINOMA OF the skin is a common lesion. It occurs on any cutaneous surface but chiefly on the skin of the head and neck. It is found in both sexes and at all ages, but elderly persons are usually the ones afflicted. The two general types of this lesion are the basal cell carcinoma of the skin and the squamous cell (epidermoid) type, usually cornified. The former arises from the basal layer, the latter from the squamous layer of skin. Lesions of the prickle cell type, of the intermediate layer of the skin, are called mediocellular carcinomas and clinically act like the basal cell lesion. Distinction between the two fundamental types is important: the basal cell lesion does not metastasize but infiltrates locally, enlarges and ulcerates to form the so-called rodent ulcer; the epidermoid lesion gains a foothold in regional lymph nodes by the passage of tumor emboli through lymphatic channels, and because of this its threat to life is greater. The rodent ulcer may grow very slowly over a period of years, and histories of existence of a lesion for 10 or more years are not unusual. The clinical course of the second type, if untreated, is usually much shorter.

The basal cell lesion frequently has a typical appearance: before ulceration takes place a nodular mass is present in the skin; it is somewhat pearly in appearance, often with multiple fine blood vessels coursing over its surface; eventually the cen-

tral part ulcerates, leaving a nodular rim. Characteristically the lesion appears in certain locations such as the angle between the nose and the cheek anywhere from the inner canthus to the junction of the ala of the nose and the cheek. However, differentiation from the cornifying squamous variety by clinical appearance and location is not reliable, since each type can simulate the other and, furthermore, the two cell types may occur in the same lesion. The only certain means of diagnosis is microscopic examination of a specimen of the lesion.

The treatment of carcinoma of the skin exemplifies a number of important points in the general problem of cancer and in radiation therapy. Because this lesion is an external one, accessible to inspection and palpation, diagnosis should always be made early in the course, in which stage almost every lesion should be successfully treated. In practice, a considerable number of advanced lesions are seen. some because of neglect on the part of the patient, others because a physician either did not recognize the nature of the disease and temporized with it or, having made a correct diagnosis, treated the lesion ineffectively with surgery or radiation. Early diagnosis and complete, efficient treatment at the first attempt will result in cure in virtually every case.

Treatment may be by surgical or radiation methods. Although small lesions may be expeditiously treated by massive doses of x-rays administered in one to several days, the best results from the viewpoint of cosmetic appearance are to be obtained by more protracted treatment. Such an approach will reduce the extent of cutaneous atrophy, eliminate postirradiation induration and subepidermal fibrosis and leave skin that can tolerate traumatic and other insults without developing foci of radionecrosis. The dose varies with different workers and with different qualities of radiation but is generally 3,000 r or more of superficial radiation. Our own technic calls for 5,000–6,000 r, as measured in air, in a period of 10–12 days. Larger lesions usually receive more prolonged fractional irradiation to high total dose. Lesions which are large in area and in depth must be irradiated with high voltage, generally 200 kv., with

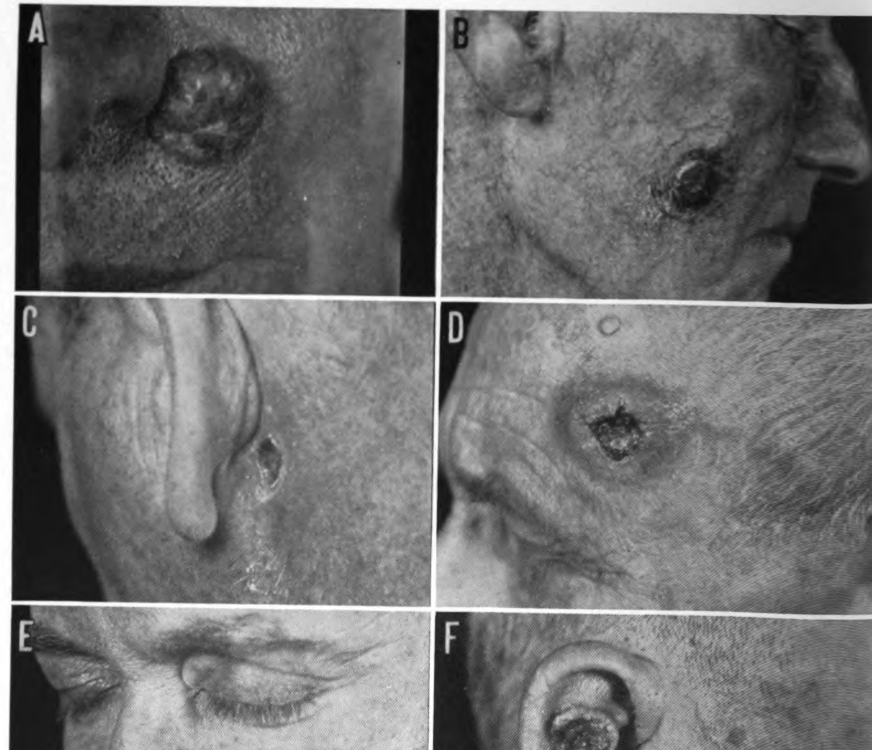


PLATE 86

small daily doses to larger totals; for these the time of administration of the dose may extend over four to six weeks. Radium treatment, gamma not beta ray, given by means of surface application or interstitial sources is effective but lacks the technical simplicity, flexibility and wide applicability of x-ray treatment. Frequently the choice between x-ray and radium treatment depends less on the character and location of the neoplasm than on the experience and equipment at the disposal of the radiologist. Not the kind of radiation but the efficiency of utilization is the important factor.

Basal cell lesions are generally considered to be more sensitive to radiation than the epidermoid variety and some workers give them smaller doses, but the not infrequent occurrence of both cell types in the same tumor makes such a distinction inadvisable.

Carcinoma of the skin occurs frequently on the nose and is not uncommon on the ear. The danger of cartilage necrosis with radiation treatment in these sites has been stressed, in fact, overstressed, because in the average-sized lesion its incidence is remarkably low even with massive dose technics. Since surgical excision at these sites usually means mutilation, the small risk of necrosis is accepted. Should necrosis occur, excision of the involved area can be carried out later, if necessary, with no greater deformity resulting than that from initial excision. With advanced lesions obviously invading cartilage and usually harboring secondary infections, the incidence of necrosis is greater, but the advanced state of the disease often makes the surgeon reluctant to perform the excision and irradiation is employed.

But this does not mean that irradiation is indicated in every case of carcinoma of the skin. It may be highly inadvisable to re-irradiate lesions recurring after previous radiation treatment

---

←PLATE 86.—Carcinoma of skin. *A*, basal cell carcinoma; *B*, cornifying squamous cell carcinoma of right cheek and of right side of nose; size of field of irradiation shown. *C*, basal cell carcinoma, assuming form of simple ulcer; *D*, cornifying squamous cell carcinoma, ulcerated in central portion; *E*, mediocellular carcinoma (rodent ulcer); *F*, cornifying squamous cell carcinoma of ear; *G*, mediocellular carcinoma of nose; *H*, extensive basal cell carcinoma; fields irradiated shown.

PLATE 87

and excision may then be the indicated form of therapy. Lesions arising in burn scars are poor candidates for irradiation because the avascularity of the tumor bed often will prohibit recovery from the sharp radiation reaction. In the aged, carcinoma of the skin of the dorsum of the hand is fairly common; the atrophic character of the skin and subcutaneous tissues makes tolerance of radiation reaction low and excision may be preferable. Carcinomas arising in areas of chronic radiation dermatitis are not suitable for radiation treatment.

Except in unusual circumstances there is no need, in the treatment of the primary lesion, to combine surgical and radiation methods. Efficient execution of either form of therapy suffices. Radiation effect is not additive to surgical effect and inadequate surgery plus insufficient radiation dose do not add up to good treatment. A partial excision or destruction of the lesion does not warrant the use of a smaller dose of radiation. Whether the attack is by surgery or by radiation, an adequate border of normal tissue must be included; the basal cell lesion in particular is notorious for infiltrating beneath apparently normal skin.

Carcinomas, almost always of the basal cell variety, involving the skin of the eyelids are fairly common. Their proximity to the eye does not contraindicate radiation treatment, since with x-ray irradiation the globe can be protected by shields introduced into the anesthetized conjunctival sac and excellent cosmetic results can be obtained without producing radiation cataracts.

As far as results are concerned, localized, previously untreated, basal cell carcinomas should be cured in 95 or more per cent of the cases. The percentage of cures of the other type of skin cancer is somewhat lower because on occasion even a

---

←PLATE 87.—Carcinoma of skin. *A: left,* mediocellular carcinoma; stained area is site of biopsy; *right,* complete regression after irradiation. No recurrence at time of death 6⅓ years later. *B: left,* basal cell and cornifying squamous cell carcinoma; *right,* complete eradication by irradiation without recurrence 5½ years later. Note mild cutaneous atrophy. *C: left,* poorly differentiated carcinoma of left preauricular region; *right,* three years after successful radiation treatment. The patient died without recurrence 4½ years after treatment.

PLATE 88.—Carcinoma of skin. *A: left,* extensive basal cell carcinoma (rodent ulcer) of nose and cheek destroying inner canthus and medial part of lower eyelid; ulceration extends down to bone. *Right,* six months after irradiation, neoplasm eradicated and ulcer slowly healing. *B: upper left,* cornifying squamous cell carcinoma of left cheek; field of irradiation outlined. *Upper right,* radiation reaction 2½ weeks and, *lower left,* six weeks after treatment; reaction healed uneventfully with eradication of neoplasm; *lower right,* eight months after irradiation.

small lesion will metastasize and the treatment of metastasis is a much more serious problem than that of the primary lesion. Obviously, the more advanced the lesion the poorer the results and, unfortunately, even today hopelessly far-advanced cases of this disease are still encountered.

CARCINOMA OF THE LIP

The treatment of carcinoma of the lip, like that of carcinoma of the skin, is a fruitful field for radiation therapy. The lip constitutes an ideal tumor bed for the tolerance of radiation reaction, and in many instances metastasis to the lymph nodes occurs late in the course. Carcinoma of the lip as defined here refers to the epithelial malignancy which arises from the vermilion surface of the lip and is almost always a cornifying squamous cell carcinoma or a less well-differentiated neoplasm of this type; basal cell carcinoma of the vermilion surface is rare. Lesions arising on the skin surface of the lip are classified as cutaneous carcinomas.

The lesion usually develops on the lower lip and is more common in men, although cases of upper lip involvement and occurrence in females are not uncommon. Like other forms of cancer its incidence is high in the elderly, but youth is no barrier to its occurrence. From a diagnostic point of view the principle to be kept in mind is that *any* lesion developing on the vermilion surface of the lip which persists for three to four weeks without healing or showing unequivocal evidence of progress toward healing should be biopsied. To temporize with a lip lesion because it is not typically neoplastic in appearance may be hazardous. To submit a patient having positive blood reaction to antisyphilitic therapy to rule out a syphilitic lip lesion is inadvisable and dangerous because of the delay involved.

The very early carcinoma of the lip may appear only as a small nodularity with slight scaling or excoriation of the vermilion surface. As it enlarges it will extend to involve the adjacent skin, labial and buccal mucosae and infiltrate into the substance of the lip almost to the chin; it will become ulcerated and fissured, and will destroy variable portions of the lip. Regional

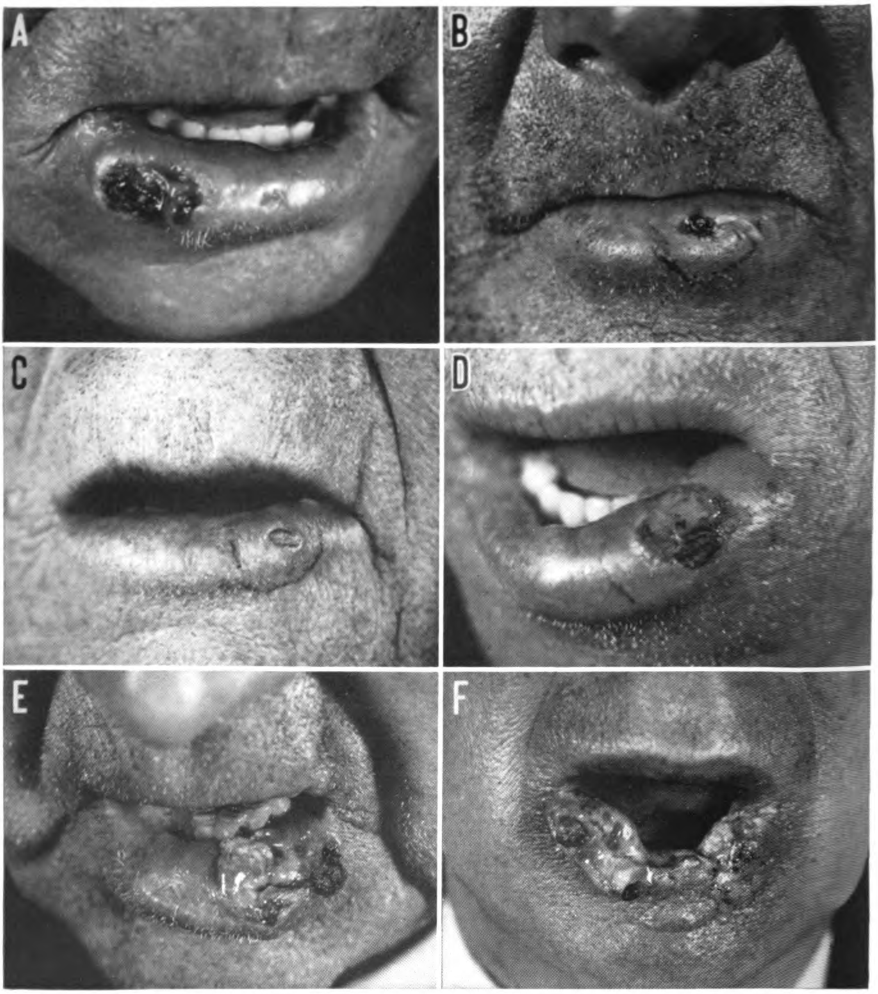


PLATE 89.—Carcinoma of the lip. *A,* characteristic appearance of carcinoma of lip (after irradiation, the lesion disappeared and at time of death 3½ years later had not recurred). *B,* small crusted area in lower lip persisting for four weeks. Biopsy disclosed cornifying squamous cell carcinoma. (The patient died without recurrence 8⅜ years after irradiation). *C,* small carcinoma with central ulceration and proliferative margin (no recurrence 9½ years after irradiation). *D,* carcinoma appearing as a superficial ulcer; it had recurred after surgical excision (no recurrence 7⅛ years after irradiation). *E,* advanced infiltrating carcinoma with ulceration and fissuring (no recurrence 10 years after irradiation). *F,* far-advanced recurrent carcinoma destroying most of lower lip and infiltrating toward chin (radiation and surgical treatment failed).

bone may be invaded. Metastases will occur first in the lymph nodes of the submental and submaxillary areas. Some lesions are largely proliferative and form large tumors projecting above the surface.

Carcinoma of the lip cannot be considered a radiosensitive lesion in the sense that it will melt away with small radiation doses. Large doses are required and sharp radiation reactions must be evoked for eradication. The normal lip tolerates such reactions well, healing with only mild or moderate postirradiation changes. Although adequate V-shaped excision will give excellent results, radiation has the advantage of producing a better cosmetic result with equal if not better eradication of the malignancy. Either x-ray or radium technics may be employed. With the latter, some men favor surface application whereas others prefer interstitial implant; either method will give good results if effective technics and adequate doses are used. As in the case of the cutaneous carcinomas, however, x-ray treatment offers technical flexibility and simplicity which permits wide application with precision to the various anatomic types of lip carcinoma that cannot be equaled by radium technics. The general technic of x-ray irradiation is similar to that employed in lesions of the skin. Although the small lesions may be treated in a short time—even in one day—with massive doses, the best cosmetic results with minimal or negligible postirradiation changes are obtained by more prolonged irradiation. If rapid treatment is imperative, the most expeditious approach to small lesions is adequate surgical excision. In general the radiation dose to a small lip lesion is administered in not less than 10 or 12 days. Extensive lesions are adequately managed only by high voltage, well-filtered, fractional irradiation extending over a period of weeks. Residual defects in the lip after proper irradiation will be due not to radiation destruction of tissue but to destruction wrought either by the neoplasm or by the surgical excision or the cautery done before radiation treatment.

The treatment of the average- or small-sized carcinoma of the lip no longer constitutes a therapeutic problem, for adequate radiation technics will destroy this lesion with minimal cosmetic alteration. Recurrences following well-executed radiation ther-

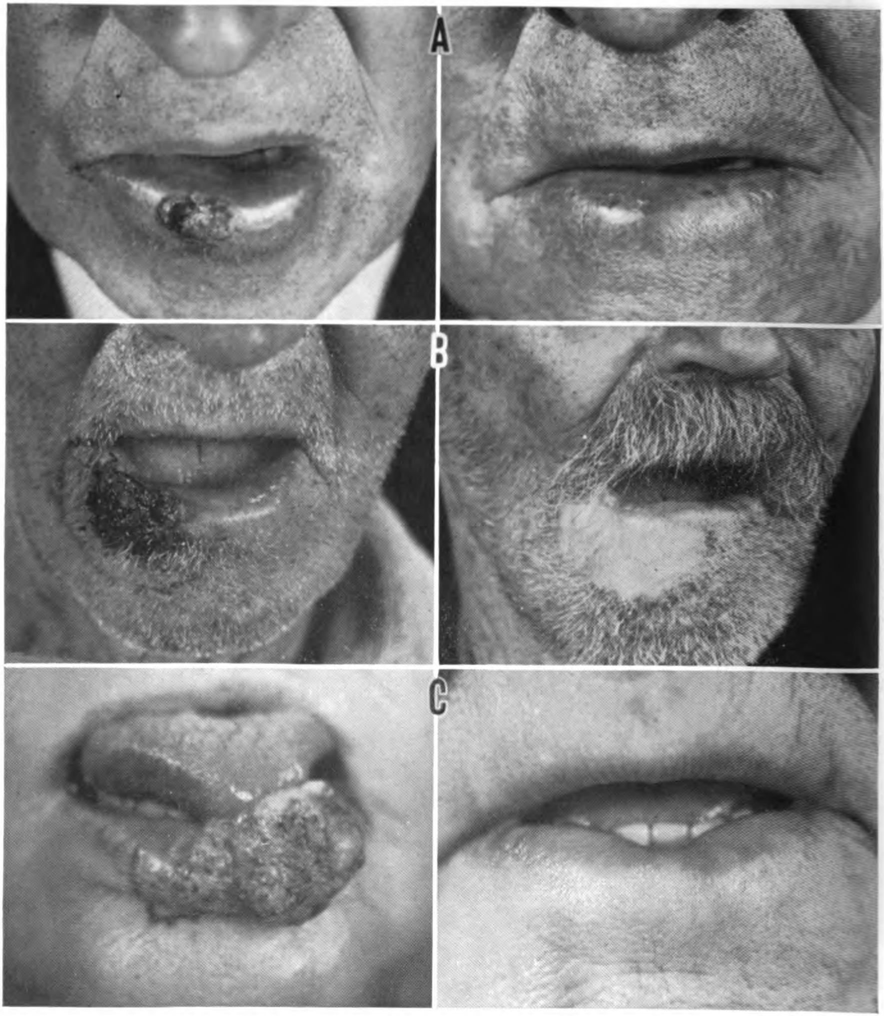


PLATE 90.—Carcinoma of the lip. *A: left,* moderate-sized carcinoma of lip; *right,* complete disappearance after irradiation, with no recurrence at 10½ years. *B: left,* large carcinoma; field of irradiation shown; *right,* complete eradication of neoplasm. Note epilation in irradiated zone. No recurrence at death 4½ years after treatment. *C: left,* fungating carcinoma in elderly woman; *right,* complete disappearance after irradiation. Note essentially normal configuration of lower lip. No recurrence 6⅙ years after treatment.

PLATE 91.—Carcinoma of the lip. *A: left,* huge fungating carcinoma of lower lip; *right,* on last day of high-voltage fractional x-ray irradiation, lesion has decreased markedly, sharp radiation reaction is present. Subsequently all clinical evidence of carcinoma disappeared and no recurrence was present 6¾ years after treatment. *B: left,* far-advanced proliferative and ulcerative carcinoma; *right,* complete regression after fractional external irradiation. No recurrence at death 3¼ years later from cerebrovascular accident. *C: left,* far-advanced lower lip carcinoma destroying left angle of mouth, invading cheek and upper lip; *right,* clinical absence of carcinoma after irradiation. No recurrence at death from carcinoma of prostate 4½ years after treatment.

apy of sufficient dosage are uncommon. The well-advanced lesions and those producing lymph node metastases still present difficulties. Many patients with previously untreated small- or moderate-sized lip lesions are seen without clinically demonstrable metastases. Probably 1 of 20 such patients will harbor microscopic metastases in the lymph nodes of the submental or submaxillary regions. After radiation treatment of the lip lesion, patients are closely observed. Should clinical metastatic disease appear, a surgical dissection of the lymph nodes is carried out. It is important that the patients be seen at monthly intervals for the first year after treatment of the primary lesion; only rarely will metastatic disease appear after that time. The probability of existing lymph node metastasis even though not clinically demonstrable increases with recurrent and advanced lesions as well as those with highly anaplastic and bizarre histopathology. In these, more consideration should be given to neck dissections immediately following control of the primary tumor. Some patients will present themselves with both the primary tumor and obvious lymph node metastases. At times in such cases, in order not to delay attack on the metastases, surgery may be used for the primary lesion in addition to the neck dissection. For the treatment of cervical metastases from lip lesions, the surgical attack is preferable provided the disease is operable. The radiation treatment of such metastatic disease can be successful only to a limited extent, namely, if focal involvement permits the introduction of a large dose in a limited volume of neck tissue.

In 160 cases of carcinoma of the lower lip seen in 1940–45, including lesions recurrent after treatment elsewhere and many advanced lesions such as those illustrated in Plates 89–91, the five year cure rate was approximately 80 per cent.

CARCINOMA OF THE ORAL CAVITY

The common malignant tumor of the oral cavity is the squamous cell carcinoma arising from the mucous membrane. Infrequently, types of carcinoma are found which originate in the mucous and salivary glands rather than in the epithelium

of the mucosa proper—these are classed with the large group of salivary gland tumors. Other malignant tumors, chiefly sarcomas, do occur but are uncommon. The squamous cell carcinoma may arise from any mucous surface in the mouth—buccal, lingual, alveolar and palatal, as well as the floor of the mouth—and frequently is well differentiated histologically, exhibiting cornification. Many of these lesions, especially of the buccal mucosa, develop on the basis of pre-existing leukoplakia; in the tongue they may be associated with syphilitic glossitis.

Despite early symptoms and the ready accessibility to inspection, the diagnosis, unfortunately, often is made only after the disease has progressed to an advanced state. The correct diagnosis is made early if, in the presence of any oral lesion, the possibility of malignancy is considered and microscopic examination of a removed specimen is carried out. This is of particular importance in leukoplakic areas which show thickening or suggestive nodulation. The results of treatment can be brilliant with small, localized lesions which have not metastasized, but when invasion of the mandible or the superior maxilla has taken place, or if the cervical lymph nodes become involved, the probability of cure falls sharply.

Irradiation plays a large part in the treatment of carcinoma of the buccal mucosa and finds application in both the small, early lesions and the advanced ones. Local surgical excision of small lesions can give good results; irradiation does equally well. With more advanced lesions surgical methods entail excision of the entire thickness of the cheek, necessitating plastic reconstructive procedures. Because of the nearness of the buccal lesion to the surface large doses can be introduced even by external irradiation and these are well tolerated. A favorable aspect of carcinoma of the buccal mucosa is that on the whole it tends to metastasize late, acting, in this respect, more like that on the lip than that on the tongue. The radiation approach to this lesion may be by external x-ray or radium, peroral x-ray or interstitial and surface radium, used singly or in various combinations. Determination of which is best to use will rest on the size and configuration of the lesion and its location on the buccal surface. Many lesions can be eradicated by high-voltage, daily

fractional treatment carried to the point of a vigorous reaction in the skin and mucosa. Many lesions will regress during the course of such treatment so that at time of completion no evidence of neoplasm is visible. As the radiation is introduced day by day, the mucosa becomes increasingly erythematous and a patchy white or yellow membrane forms which coalesces to cover the area completely. At the same time changes are seen in the neoplasm: its surface becomes filmy and the irregular projecting points of tumor tissue lose their angular contours, become rounded and gradually recede in height. Regression to the level of the normal mucosa takes place and the whole area becomes covered by a membranous mucositis. The skin and mucosal reactions heal during the few weeks following treatment, leaving surprisingly little permanent change in the appearance of the buccal mucosa considering the vigor of the radiation-induced inflammatory process in its acute stage.

Peroral x-ray irradiation has proved to be an excellent method of treatment in many buccal carcinomas. Often it may be combined with external treatment, but when the lesion can be adequately covered by the peroral cone this may be unnecessary. Surface application of radium on the tumor is used by many workers and some employ interstitial sources frequently. As has been mentioned in relation to other lesions, the choice between x-ray and radium often depends less on the characteristics of the neoplasm than on the background of the physician carrying out the treatment. There is no inherent advantage of radium over x-ray, but there are occasions when the particular distribution of ionization about a radium source is valuable. Among 50 cases of buccal carcinoma seen since 1940 and treated by radiation methods, the five year cure rate was 46.4 per cent.

The lesions arising on the alveolar mucosae present special problems because of the adjacent bone structures—the mandible and the superior maxilla—and the presence of teeth. Because of the impairment of bone vitality by heavy irradiation it is unwise to permit the patient to retain the teeth in the irradiated portion; on extraction, performed even years later, the bone may not withstand the trauma or the infection which enters through the dental socket, and necrosis may ensue. Extraction should be car-

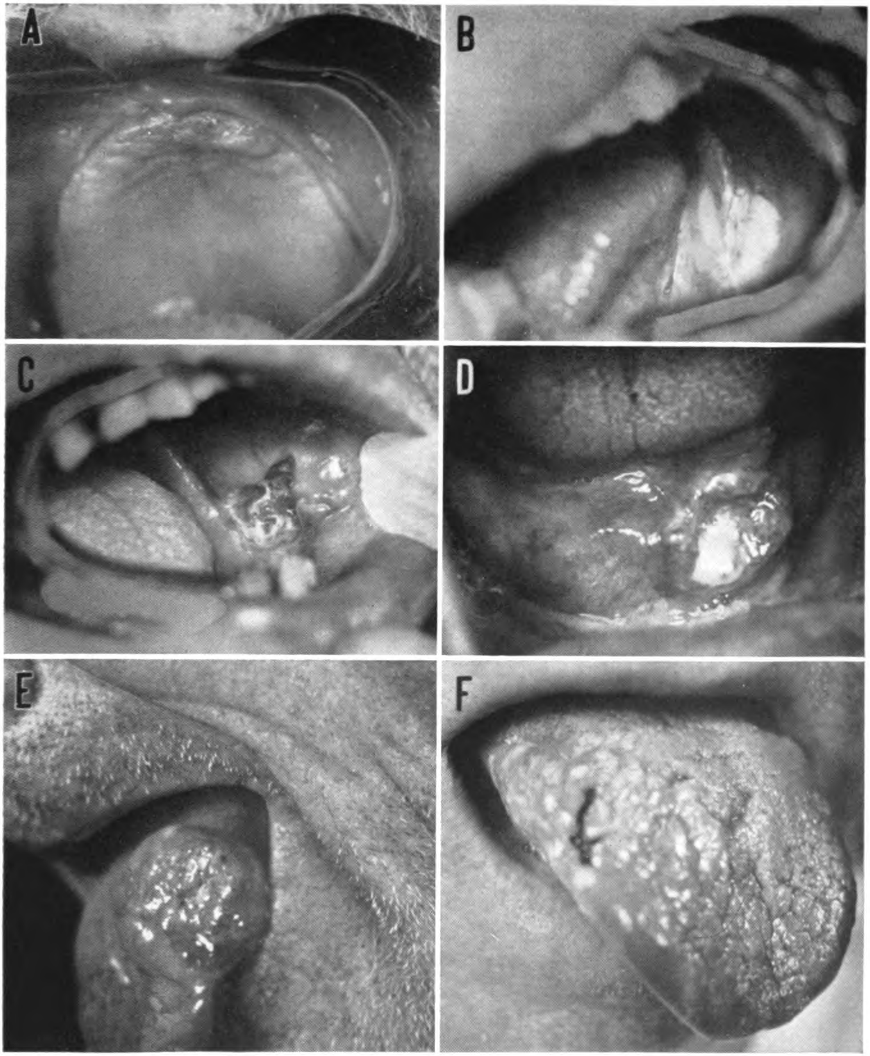


PLATE 92.—Oral carcinoma. *A,* small carcinoma of upper anterior alveolar mucosa assuming form of simple ulcer; *B,* carcinoma of left buccal mucosa arising in leukoplakia and appearing as thick leukoplakic patch; *C,* advanced ulcerating carcinoma of left buccal mucosa; *D,* carcinoma of floor of mouth with rolled margin and central ulceration; *E,* carcinoma of left lateral aspect of tongue; *F,* large carcinoma occupying major part of right half of tongue; suture at site of biopsy.

ried out before radiation treatment is begun. Because of the high ionization intensity surrounding the radium needles and seeds, interstitial irradiation results in excessive damage to the bone and therefore is usually contraindicated. If the bone is invaded by the carcinoma, especially in the face of an open, ulcerating tumor, osteonecrosis usually but not inevitably ensues. Before radiation treatment is decided on it is essential to examine the bone radiographically to determine the presence or absence of invasion. When present, surgery may be the treatment of choice provided the extent of soft tissue involvement is not too great to preclude the possibility of complete excision. Surgical treatment involves resection of a portion of the bone. Bone invasion not only predisposes to osteonecrosis but makes eradication of the invading cells by irradiation extremely difficult but not impossible. When tumor has not entered the bone, carcinomas of the alveolar mucosa can be treated by radiation methods with good results. Such carcinomas occurring in the upper jaw present a special diagnostic aspect which must always be borne in mind for they must be differentiated from carcinomas of the antrum invading the alveolus. This is important because the treatment of the antral lesion is quite different and the prognosis is considerably worse.

Carcinoma of the mucosa of the hard palate also must not be confused with lesions of antral origin. Because of the adjacent bony palate, the discussion regarding bone invasion is also pertinent here, although it seems possible with x-rays to treat these lesions successfully with somewhat less danger of complications than in the lower jaw. As in the lesions of the alveolar mucosa radium implantation is rarely advisable. The carcinoma of the soft palate acts quite differently from that of the hard palate; it often tends to be more anaplastic and metastasizes to the cervical nodes earlier. Clinically and in its reaction to radiation it resembles carcinomas of the tonsillar region, the pharynx and nasopharynx and, like them, is usually treated with external irradiation frequently supplemented by peroral treatment. The possibility must not be overlooked that a carcinomatous lesion in the soft palate may not be primary there, but may represent an extension from the tonsillar region or the nasopharynx. The

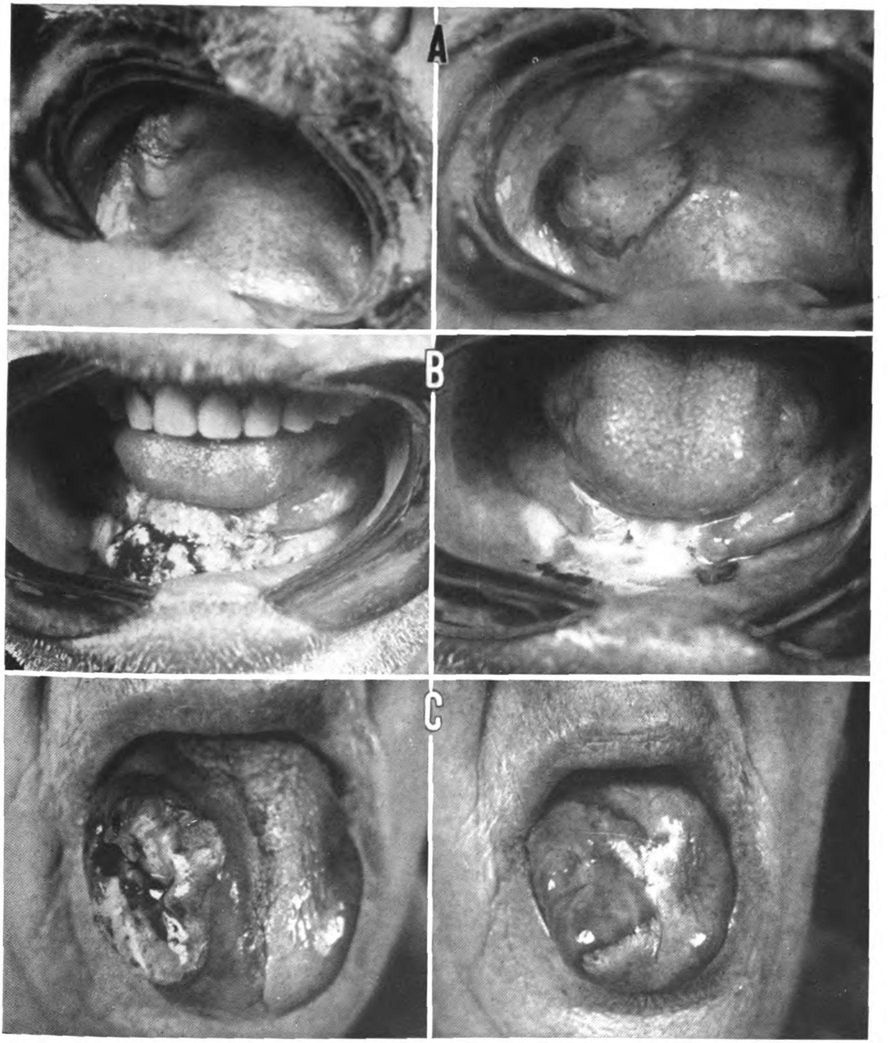


PLATE 93.—Oral carcinoma. *A: left,* small verrucous-like carcinoma of right upper alveolar mucosa with leukoplakia in mucobuccal fornix; *right,* complete regression of lesion at close of peroral irradiation; radiation mucositis present. *B: left,* carcinoma of floor of mouth; *right,* no clinical evidence of carcinoma on completion of peroral irradiation; membranous mucositis (radiation reaction) present. *C: left,* carcinoma of right half of tongue; *right,* regression of lesion after peroral irradiation; radiation reaction present.

tumors arising from mucous glands and classed with the general group of salivary gland tumors probably appear more commonly in the hard and soft palatal mucosae than in any other portion of the oral cavity and are predominantly surgical problems.

The carcinoma arising in the mucosa of the floor of the mouth often proves difficult to eradicate by any method of treatment. Local excision is more often than not inadequate; radical excision is a formidable procedure resulting in considerable deformity and functional disability. Radiation methods are commonly used for this disease. External irradiation through multiple fields, concentrating the dose in the tumor area and combined with either interstitial radium implant or peroral x-ray irradiation, constitutes the procedure of choice. In some advanced lesions treatment may have to be limited to external irradiation alone; some cures may be obtained in this fashion but the percentage is low. Among 47 patients with carcinoma of the floor of the mouth irradiated since 1940, the five year cure rate was 28.4 per cent.

Carcinoma of the tongue constitutes a difficult therapeutic problem in which surgical attack on the primary lesion has largely been replaced by radiation methods. In general the lesions arising in the oral portion of the tongue are well-differentiated squamous cell carcinomas which usually are cornifying. The lesions originating in the base of the tongue, that is, the part in the pharynx, tend to be less well differentiated. High doses of radiation are required for eradication of both types and, although it may seem paradoxical, the results are better in the oral lesions. The lingual carcinoma readily infiltrates the regional tissue, and most lesions are actually larger than inspection and palpation indicate. Excision must be wide to be successful and much more of the tongue must be removed than would appear necessary to the inexperienced observer. Thus, even with relatively small lesions localized to a lateral aspect of the organ, a resection almost to the extent of a hemiglossectomy is required; with lesions approaching the midline most of the tongue should be resected—a procedure obviously undesirable.

Experience has shown that every lingual lesion which can be controlled by surgical excision can be eradicated by adequate irradiation and, in addition, many primary tumors which have

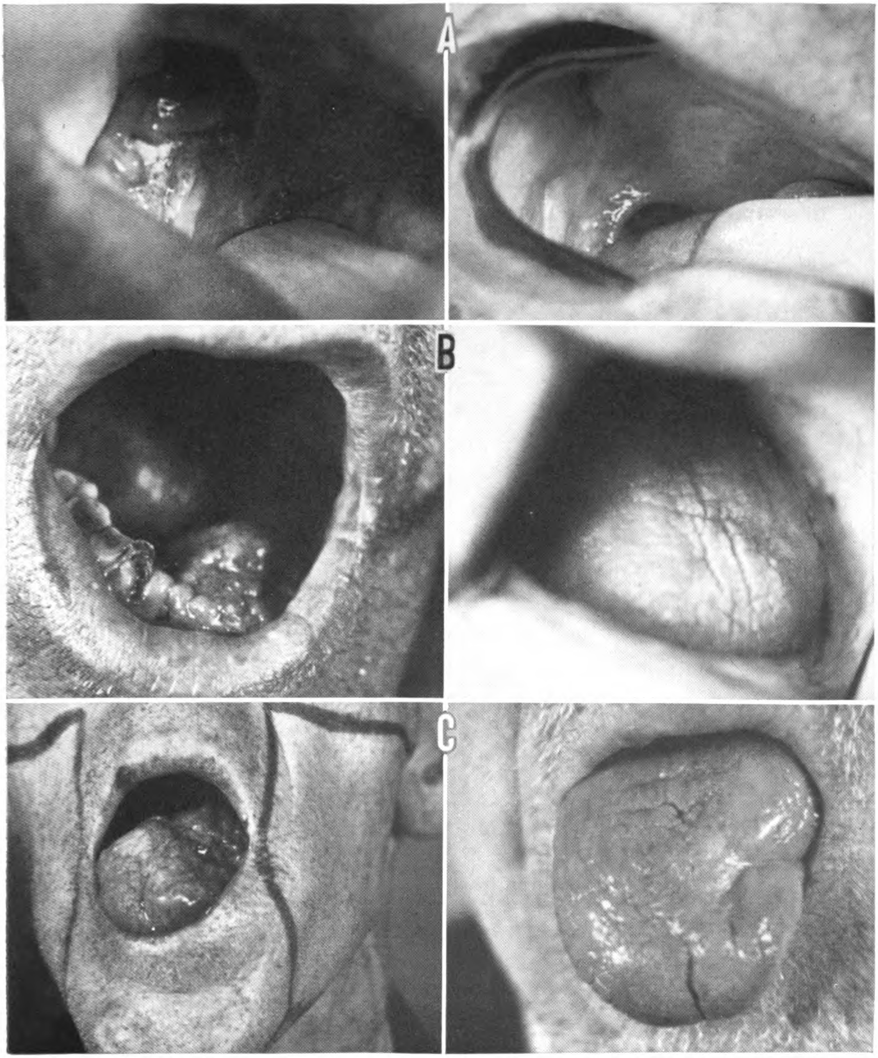


PLATE 94.—Oral carcinoma. *A: left,* carcinoma of right buccal mucosa; *right,* complete regression after peroral irradiation; no recurrence or metastasis eight years later. *B: left,* far-advanced carcinoma of alveolar mucosa and floor of mouth with invasion and destruction of mandible; *right,* no recurrence 4½ years after external irradiation. Despite invasion of mandible, osteonecrosis did not occur. *C: left,* advanced lingual carcinoma; *right,* disappearance after external irradiation. Later, cervical metastases appeared.

advanced to a stage uncontrollable by surgical means, short of total glossectomy, can be destroyed. Failure to cure carcinomas of the oral part of the tongue is due more often to inability to cope with cervical metastases than to failure to control a primary tumor. As with the other oral lesions, the radiation treatment may involve any of the available methods, but in all a high dose must be built up in the tumor. A favored approach is the insertion of needles of low radium content (such as 1 mg. per cm.) for five to seven days. Radium treatment may be combined with external irradiation by implanting needles or seeds in residual tumor tissue. Peroral x-ray irradiation can be an excellent method, when applicable; daily doses of 150–300 r are given each day, using 200 kv. filtered radiation to a total of about 7,000 r as measured in air. The area on the tongue that can be irradiated is limited by the size and type of cone that can be introduced into the open mouth. Commercial equipment of this type is unsatisfactory because of the rigidity and thickness of the walls of the cones. With a thin-walled cone made to fit the individual patient, this technic can be used more often and more satisfactorily than has been the case in the past.

The healing of the sharp radiation reaction following the necessary large doses may be protracted but does occur. A sequel which may develop months or even a year or two after treatment is necrosis of soft tissue. A small, painful area containing many tiny, reddish-purple spots appears; then a shallow, superficial ulceration develops, the base of which is yellow and the margins fairly sharp. Pain is the dominant symptom and appears excessive for the findings present. After several weeks healing may take place. Sometimes the tissue destruction advances to form a fairly deep ulcer with obvious necrotic tissue in its base, and excision of the area may be necessary to obtain healing. Such reactions may be mistaken for neoplastic recurrence; since they are necrosis of tissue due to devascularization as a result of irradiation, further radiation treatment would only increase the necrotizing process. In any type of oral carcinoma in which the chance of secondary infection is good, particularly after interstitial irradiation, when such a breakdown occurs a progressive process may develop which clinically simulates advancing

neoplasm. In such cases months may elapse before the true nature of the condition becomes apparent through evidence of healing.

The carcinomas developing in the base of the tongue, that is, in the pharyngeal part of the organ, are usually not well differentiated histologically and act like carcinomas of other parts

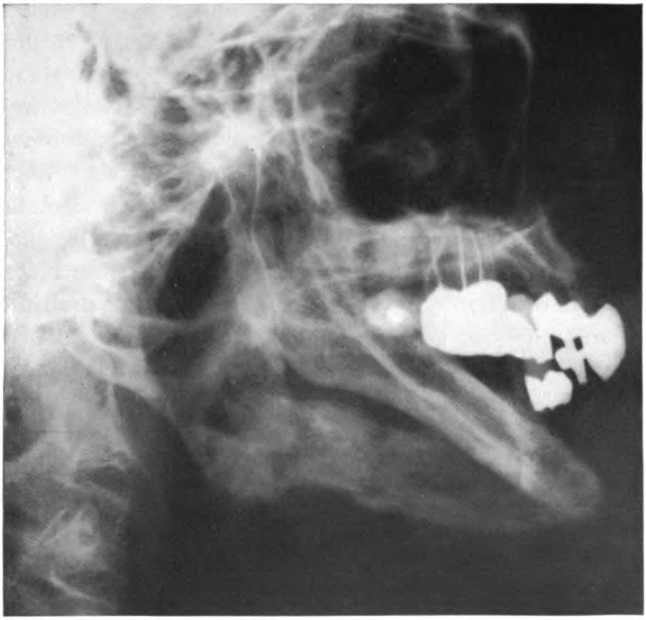


PLATE 95.—Osteonecrosis and sequestration of horizontal ramus of mandible following external and interstitial radiation treatment of carcinoma of the tongue. The sequestrum was removed shortly after this roentgenogram was made and healing took place rapidly.

of the pharynx. At this site neither surgery nor local radium technics are satisfactory, and reliance on eradication must be placed on external irradiation. Many of these lesions are radioresponsive, but the end-results are considerably poorer than in carcinoma of the oral part of the tongue. One reason for this is that these lesions are rarely diagnosed before fairly extensive bilateral cervical metastases have developed.

The management of the cervical nodes in malignant lesions of the mouth and tongue frequently presents perplexing problems and the treatment of obvious metastases is fraught with difficulties. When such metastases are present, if the neoplasm is fairly well differentiated and the involved nodes are not fixed it is generally accepted that the block-type, neck gland dissection, usually radical, should be done. With anaplastic histology, penetration of the capsule of the lymph node and permeation of the interstitial tissue causing fixation, the results of surgery are poor and the procedure is inadvisable. Such cases are treated by radiation methods and, although in general the results are poor, some patients may be saved and a larger number may have large masses reduced in size and pain alleviated. The most favorable of these advanced conditions are those in which the metastases are present at one site in the neck for into such lesions large quantities of radiation can be introduced. When the metastases are distributed unilaterally or even bilaterally over multiple sites the patient may not be able to tolerate the quantity of radiation necessary for destruction of the tumor tissue.

A perplexing problem is what to do when findings are negative on physical examination of the neck and the primary oral lesion has been controlled or the probability of controlling it seems high. In such lesions as the buccal carcinoma, in which metastases tend to occur late, usually the neck is kept under careful observation and operation carried out only if metastases develop. The carcinoma of the tongue metastasizes with much greater frequency than the buccal lesion and patients without clinical evidence of metastases may harbor microscopic lesions. It seems probable that removal of the lymph nodes at any early stage should carry a much greater chance of cure than after the nodes are completely replaced by carcinoma. Since the metastases involve the deep as well as the superficial cervical nodes, only radical neck gland dissection will suffice. Furthermore, when the lingual lesion extends close to the midline of the tongue the chance of bilateral metastases is increased and bilateral neck gland dissection becomes necessary. A properly executed, unilateral, radical neck gland dissection is not a simple procedure and carries a mortality risk which may be as low as

3 per cent in expert hands and as high as 10 per cent in other hands. The bilateral procedure is formidable and is considered inadvisable by many experienced workers. In face of such difficulties the temptation to postpone any surgical treatment of the neck is great if there is no evidence of metastasis.

A retrospective analysis of our cases, in which prophylactic neck dissections were carried out only to a limited extent, has demonstrated that a consistent policy of prophylactic dissections would have resulted in a negligible improvement of the survival rate. A similar analysis of 247 cases of carcinoma of the oral part of the tongue reported by F. Jacobsson[1] gave a similar result. It is believed that a policy of frequent post-treatment examinations, preferably at monthly intervals for the first year and somewhat less often thereafter, with meticulous examination for nodes suspicious of metastasis and immediate neck dissection when found, will produce at least as good results as prophylactic dissections and at a lesser cost in terms of number of operations, morbidity and so on. If proper follow-up control of the patient is not possible, prophylactic dissection will warrant consideration.

Prophylactic irradiation of the neck is not done when the findings are negative. Small doses have no value, and it is impossible to deliver a cancerocidal dose to all the cervical nodes of the neck.

Among 113 patients with carcinoma of the oral part of the tongue seen since 1940, the five year cure rate was 38 per cent.

(1) Jacobsson, F.: Carcinoma of the tongue, Acta radiol., supp. LXVIII, 1948.

11

The Head and Neck

Carcinoma of the Nasopharynx, Tonsil, Pharynx and Larynx

THE MALIGNANT lesions of the tonsil, pharynx and larynx constitute an important field for radiation therapy. With the exception of certain carcinomas within the larynx, surgical measures have been able to offer practically nothing to patients afflicted with these tumors. Most of these lesions are advanced when first seen; the primary lesion is large and the incidence of metastases is high. Before the advent of radiation therapy virtually every patient harboring such a tumor was doomed. About 25 years ago Coutard demonstrated the radiocurability of some of these neoplasms. The results of radiation treatment are not brilliant; they vary with different sites and histologic types and with the extent of the disease but, on an average, freedom from neoplasm five years after treatment is found in 15–30 per cent of the cases. When one realizes that most of these lesions are advanced when irradiation is undertaken, that they are aggressively malignant in their local growth and ability to metastasize and that no other method has anything significant to offer, such rates of curability represent an important advance in cancer therapy. It must not be forgotten that, besides curing some patients, irradiation may offer palliation to many more in relief from pain, reduction in size of large masses and the healing of ulcerating tumors.

The diagnosis of the early stage of a carcinoma arising in the mucosa of the nasopharynx is a rare event. The symptoms produced are minimal until the primary tumor has become large enough to cause nasal obstruction or bleeding because of ulceration, or has invaded the floor of the skull to produce various cranial palsies. In most cases the lesion is discovered only after it has produced cervical metastases. In every case of metastatic carcinoma of the neck, particularly in the upper part, in which an obvious primary tumor is not present, the nasopharynx must be carefully examined. The primary lesion may be very small and sometimes is clinically unrecognizable, but despite its insignificant size it can give rise to bulky cervical masses.

Carcinomas of the nasopharynx are almost always poorly differentiated, anaplastic lesions. Other types of tumors do occur in this region but are rare in comparison with undifferentiated carcinomas. Lymphosarcomas and mixed tumors of the salivary gland type are found. An interesting but uncommon lesion is the vascular fibroma of this region which is seen in persons under age 25. Sometimes this tumor is so cellular as to be considered sarcomatous, yet the interesting feature lies in the apparently authentic reports of its spontaneous disappearance after the age of 25.

The nasopharyngeal carcinoma responds well to irradiation and rates of cure of about 25 per cent have been reported by a number of workers. Vigorous external x-ray irradiation is the usual method of attack, with the radiation delivered through multiple fields on the head. Right- and left-sided lateral fields large enough to include both the base of the anterior portion of the skull and the upper neck are used, together with a central anterior face field or, more commonly, two anterior fields directed through each superior maxilla. Fractional daily treatments are given over five to six weeks. Local surface radium application or peroral irradiation has at times been used to supplement the x-ray dose.

The carcinoma arising in the tonsil, like that of the nasopharynx, is a poorly differentiated squamous cell lesion. Lesions originating in the mucosa of the anterior or posterior pillars at times are fairly well differentiated, but the true tonsillar tumor

is almost always anaplastic. Although the carcinomas of the tonsil and the tonsillar region may become bulky without breaking down, the usual picture is that of an ulcerating mass which may destroy the pillars and extend onto the soft palate and tongue and down the pharyngeal wall. Metastasis occurring just back of the angle of the mandible is the rule. Lymphosarcomas and tumors of the salivary gland type show a greater tendency to maintain an intact mucosa.

The treatment of carcinoma of the tonsil is entirely a radiologic problem. Technically feasible as it may appear, the surgical removal of an undifferentiated tonsillar carcinoma is of no value, since recurrence or metastasis will follow; indeed, the procedure may cause dissemination of the neoplasm. These tumors respond readily to irradiation, and extensive primary lesions and bulky metastases will regress. Many times failure to cure comes about only because of the appearance of remote metastases, such as in the mediastinum or lungs. These lesions have been successfully treated by external x-ray alone; combination of external and peroral treatment is common. Some workers prefer radium methods—external, surface and interstitial. With any of these methods, despite the rapidity of regression, the irradiation must be carried on to high tumor doses producing sharp cutaneous and mucosal reactions.

The carcinomas developing in the mucosa of the oral pharynx, that part of the pharynx just posterior to the oral cavity, also tend to be anaplastic and radioresponsive. The treatment of these tumors is also exclusively radiologic with the exception of some of the slowly growing carcinomas arising in mixed tumors of the salivary gland type. Although metastases are almost always present when the patient is first seen, complete eradication may be achieved. Treatment is limited to external irradiation.

The lower part of the pharynx, the hypopharynx, is in close anatomic association with the larynx and the carcinomas of this region are usually discussed with the laryngeal tumors. Extrinsic and intrinsic laryngeal carcinomas is a commonly employed classification. Lesions limited to the interior of the larynx are termed intrinsic. An extrinsic lesion may be one that arises in the laryngeal interior extends outside the organ or one that

originates outside the larynx, that is, in a hypopharyngeal structure. This type of classification is not satisfactory and it is best to avoid it and to speak in terms of the site of origin. However, this is not always possible, for extension of the tumor may make identification of its primary site difficult if not impossible.

The lesions that originate outside the larynx—those of the pyriform fossae, postcricoid region or hypopharyngeal walls as well as the aryepiglottic folds, epiglottis or false cords, the last three constituting the entrance to the larynx proper—tend to be poorly differentiated rather than well-differentiated squamous cell carcinomas. The lesions arising in the interior of the larynx—in the vocal cords, ventricular cavity or subglottic region —are as a rule more differentiated and frequently cornifying. The anaplastic lesions grow more rapidly and metastasize more readily: their malignant character is more aggressive.

The development of surgical technics for the treatment of carcinomas of the interior of the larynx is a brilliant chapter in surgical history. By thyrotomy small tumors of the vocal cord can be approached and resected and laryngeal function preserved; in properly selected cases eight or nine out of 10 can be cured. Half of the larynx may be resected for somewhat larger lesions and fair voice function be preserved. Still larger lesions which appear to be confined to the laryngeal interior require total laryngectomy; in these patients there is a possibility of acquiring some speaking ability either by using an artificial larynx or by developing an esophageal voice using the pharynx as a glottis. The results of total removal of the larynx are far less good than those of the more limited operations. The lesions for which the total operation is indicated are much more advanced and recurrence and metastasis are more common. The results reported by various workers are dependent in large part on the character and extent of the tumors in the selected cases.

Only a minority of the carcinomas developing in and around the larynx are suitable for surgical attack, and the actual figure is very likely less than one third of all the cases seen. The lesions arising in the larynx and extending beyond it, either by infiltration or by metastasis, plus all the tumors of extrinsic origin comprise the group not amenable to surgery in which there was no

hope of recovery before radiation methods were developed. Not all the lesions of this group have an equal chance for eradication by irradiation. Those arising from the upper part of the aryepiglottic folds or from the mucosa of the epiglottis and those of the false cords appear to give the best results. Tumors of the pyriform fossae and the postcricoid and subglottic areas carry the worst prognosis. If cartilage and bone are invaded the ability of radiation to destroy the tumor diminishes. Small lesions of the vocal cords, even though well differentiated, do well with radiation therapy, the results equaling those obtained with surgery, but most such lesions are still treated surgically. The presence of cervical metastases decreases the chance of cure but does not necessarily abolish it.

The radiation procedure for these carcinomas is not to be undertaken lightly. Usually daily fractional irradiation is carried on for five to six weeks, usually through two fields cross-firing the region of the tumor. The inflammatory reaction in the larynx and the hypopharyngeal region may be quite severe, with soreness and pain on swallowing. It may be necessary to keep the patient on a soft or even a liquid diet during this period. Often the soreness is cyclic in intensity and the daily dose may require modification during the peaks of distress. Fairly sharp skin reactions may be expected, although when the total dose is divided among several fields the acute cutaneous changes may be only moderate. The dosage range is frequently in the neighborhood of 3,000–3,600 r as measured in air to each field. Teleradium therapy is also used for these neoplasms but less commonly than x-ray. Ingenious radium technics have been developed for the treatment of laryngeal carcinomas; one is the fenestration procedure in which parts of the thyroid and cricoid cartilages are removed and radium needles set into the window so created.

If the cartilage is infiltrated by the carcinoma, not only does it become more difficult to eradicate the neoplasm but the cartilage becomes more susceptible to necrosis. Such a complication is serious and may result in death. As in the case of the mandible, the cartilage of the larynx long after irradiation is successfully carried out may, under the stimulus of trauma or infection, develop necrosis and sequestration. In view of the

possibility of such complications and the discomfort frequently suffered by patients during treatment, there must be no question about the accuracy of the diagnosis; biopsy and positive identification of the neoplasm by microscopic examination are essential.

Carcinoma of the Paranasal Sinuses

Malignant neoplasms of the accessory nasal sinuses are not rare; their incidence may be 2–3 per cent in institutions dealing only with neoplastic diseases. Most of the neoplasms encountered in these structures are carcinomas, usually of squamous cell type. Adenocarcinomas and pseudoadenomatous basal cell carcinomas (cylindroma, adenocystic epithelioma) also occur; these are probably related to the salivary gland tumors. In addition, sarcomas of various kinds are found, some of which are related to the lymphoblastomas. Tumors of the paranasal sinuses are always diagnosed late, except in rare instances when they are accidentally discovered during operation or exploration for inflammatory disease. Because of the usual extensive regional infiltration and because of the nature of the anatomic parts involved, successful treatment encounters many obstacles.

The best chance of eradicating the disease rests on a combination of surgical and radiation methods. Radical surgical procedures have produced cures, but recurrence is the rule. Radiation treatment alone, usually by external irradiation, has also succeeded in curing patients, but less often than surgery. With tumors in the sinuses and nose the incidence of secondary infection is high; when radiation is used, opportunity for drainage must be provided, and this necessitates surgical intervention. The invasion of bone by the neoplasm and the presence of secondary infection provide an excellent basis for the development of osteonecrosis after heavy irradiation, particularly if the radiation dose is unevenly distributed. Present opinion appears to favor the following therapeutic program. First, a course of external x-ray irradiation of the involved site is given through several cross-firing fields. Immediately after this the surgical procedure is carried out. This consists of electrosurgical removal of about half of the hard palate on the involved side along with the alveolar ridge to provide access to the antrum and nose. As much

of the tumor is removed as possible, also electrosurgically. The program is completed by a course of fractional radium treatment through radium sources distributed over an applicator which conforms to the shape of the cavity.

Salivary Gland Tumors

The salivary gland tumors constitute an interesting, complex and in many ways poorly understood group of neoplasms. These tumors are most commonly found in or near the salivary glands (most frequently the parotid), but apparently they can arise from the minor glands of mucosa of the mouth, nose, sinuses, trachea, pharynx, bronchi and orbits. Histologically their appearance is often complex, consisting of epithelial structures mixed with fibrous tissue that may be myxomatous and may even include cartilage cell nests. The histologic picture may be varied, especially in the malignant lesions in which are seen adenocarcinomas, pseudoadenomatous basal cell carcinomas and even squamous cell carcinomas, but less often sarcomas.

Many of these lesions are benign, and typically the history is one of a slowly growing mass in the parotid gland, often present for years. The treatment of such lesions is adequate surgical excision. In the parotid tumors the desire to avoid damage of the facial nerve often leads to incomplete removal, and sooner or later recurrence develops. Some of the malignant tumors of this group also grow very slowly; they will metastasize, but often the metastases, too, are sluggish in their growth. Pulmonary metastases may exist for years without giving rise to symptoms and their presence may be unsuspected. On the other hand, other malignant epithelial tumors of this group develop rapidly and metastasize early. When still in an operable stage, wide surgical removal followed by intensive fractional radiation treatment appears to be the best procedure. Since a number of the malignant lesions are radioresponsive, lesions which have exceeded the limits of operability should be irradiated. In some of these carcinomas, particularly the pseudoadenomatous type, remarkable palliation can be obtained by judicious radiation therapy, bearing in mind the slow rate of growth of the primary and the secondary lesions. When these tumors occur outside the parotid

and the submaxillary salivary glands, they should be correctly identified and not confused with other carcinomas more commonly occurring in the area.

Carcinoma of the Thyroid

The treatment of carcinoma of the thyroid gland is primarily a surgical problem and irradiation plays a secondary but often useful part. Most thyroid carcinomas develop in adenomas; when still confined within the capsule, thyroidectomy including total removal of the adenoma cures the patient and further treatment is not necessary. If the neoplasm has penetrated through the capsule, invading the gland, and wide surgical removal such as total thyroidectomy seems unlikely to have removed all the malignant tissue, postoperative irradiation of the thyroid region is indicated. Radiation should be applied to a high total dose; the method usually employed is daily fractional doses to skin tolerance.

Histopathologically, the malignant neoplasms of the thyroid gland have been variously classified. One classification in vogue at present divides the group into papillary adenocarcinomas (these constitute up to 50 per cent of all thyroid cancers, are the least malignant, are often seen in youth and childhood and may have an extremely prolonged clinical course); follicular and alveolar carcinomas (these often may show a remarkably orderly colloid-forming structure so that the malignant nature of the process is unrecognized until a distant metastasis appears); solid adenocarcinomas; Hürthle cell carcinomas; giant and spindle cell carcinomas as well as some other highly anaplastic lesions. Frequently tumors show a mixture of these various types. In the giant and spindle cell carcinomas, the results of treatment of any type are poor; irradiation is of extremely limited value.

The clinical picture of neoplasm of the thyroid is closely simulated by certain chronic inflammatory processes, termed Riedel's struma and Hashimoto's struma. These are probably the same forms of thyroiditis, with the latter showing marked lymphocytic infiltration and even characteristic germinal centers; lymphocytes are present in Riedel's struma but to a lesser degree. These conditions are of interest to the radiologist because irradia-

tion of Hashimoto's struma may produce involution of the process to the point of restitution of a normal gland. Without microscopic examination it is impossible to differentiate them from neoplasm, and therefore remarkable regressions in cases unverified by biopsy cannot be presented as evidence of the effect of radiation on thyroid tumors.

Besides being of postoperative value after apparently incomplete excision, irradiation may offer significant palliation in inoperable, recurrent and metastatic cases. Besides metastasizing to cervical lymph nodes, thyroid carcinomas metastasize to the lungs, bones, liver, kidney and brain. At some of these sites radiation treatment may alleviate symptoms and even cause temporary disappearance of the neoplasm. In extensive local involvement with tracheal compression, surgical excision of part of the neoplasm in the region of the thyroid isthmus, combined with radiation treatment, may relieve the patient of dyspnea for some time.

The palliative possibilities of irradiation in thyroid carcinomas are demonstrated by one patient about 50 years of age in whom nearly all the lymph nodes in the right side of the neck were involved by papilliferous adenocarcinoma; the thyroid had been removed some months previously. Following vigorous irradiation of the neck, the metastases regressed and had not recurred after more than 16 years. A second patient about 25 years of age (thyroid carcinomas are frequently found in young individuals) was seen with bilateral cervical and pulmonary metastases, the primary lesion having been removed earlier. Although the condition was considered hopeless even from the point of view of significant palliation, moderate doses were given to the involved regions; complete regression at all involved sites took place. A localized recurrence appeared in the neck five years later and was heavily irradiated. Thirteen years after initial irradiation the patient was well and had no clinical or radiographic evidence of neoplasm.

During the past decade a new form of radiotherapy for thyroid carcinoma has evolved. Radioactive iodine, I^{131}, is employed. This radioactive isotope of iodine has a half-life of 8 days and emits beta rays (maximum energy 0.6 Mev) and gamma

rays (0.37 Mev). Metabolically radioiodine is handled by the body precisely as is stable iodine. Therefore on ingestion, the element is concentrated in the thyroid gland and in certain thyroid carcinomas which have the capacity of concentrating iodine. Radiation is emitted at the sites of uptake, localizing the radiation effect in the tissue to be affected. Thus I^{131} is successfully used in the treatment of hyperthyroid disease as an alternate to surgical and medical therapy. In certain circumstances it offers significant advantages.

In thyroid cancer it has been found that certain limitations exist which make this form of therapy less productive of significant clinical results than was initially hoped. Not all of the neoplasms are capable of concentrating iodine. Spindle cell, giant cell and Hürthle cell carcinomas almost invariably fail to collect significant amounts of I^{131}. Most papillary adenocarcinomas also fail in this respect. The well-differentiated follicular and alveolar tumors containing colloid usually show a pronounced iodine uptake, but pure forms of this tumor are not common. It is not unusual to find that some tumors do not take up enough I^{131} to warrant therapy. Not infrequently the concentration in others is not uniform; also, in the same patient some metastases will and others will not concentrate iodine. Therefore some parts of the neoplasm will be irradiated and others will not. The damaging effects of radiation from I^{131} that may occur in hemopoietic tissues creates a limitation to this form of treatment. The large doses administered therapeutically in thyroid cancer while being transported in the blood and extracellular fluids (until picked up by functioning thyroid tissue) or while being excreted via the urinary tract expose non-thyroid tissues to radiation effect. Lethal pancytopenia has been produced by excessive doses.

Currently surgery and external irradiation are the indicated means of treatment of thyroid cancer limited to the thyroid gland and adjacent lymph nodes. Abandonment of these methods in such cases for attempts at treatment with I^{131} is incorrect. In metastatic disease with high avidity for iodine, significant (in isolated instances, brilliant) palliative benefit may be achieved. In certain cases, the I^{131} uptake in metastases is enhanced by total thyroidectomy. This is generally done before

I^{131} treatment is attempted. If the situation does not permit surgical removal, the thyroid gland can be destroyed by large doses of I^{131}. Thiouracil administered over relatively long periods after total thyroidectomy also may increase iodine uptake. In general it appears that of those patients whose disease has extended beyond the scope of the classic methods of treatment, 10–15 per cent are candidates for radioiodine therapy.

Metastatic Carcinoma of the Neck

A clinical situation encountered rather frequently in any practice in which many cases of malignancy are seen is found in the patient who has one or more masses in the neck which biopsy shows to be metastatic carcinoma. The patient may be unaware of a primary lesion elsewhere in the body. In some patients examination readily discloses the primary neoplasm; in others it may be impossible to find it at the initial examination. In any case presenting carcinoma in the neck which did not arise in the skin, a careful search for a primary tumor must be made. Carcinomas have been said to arise as primary lesions in the cervical region from branchial cleft remnants, but proof of such an origin is difficult, if not impossible, and is based on exclusion of other sites. Positive exclusion can be made only by a complete and careful postmortem examination.

The location and histologic character of the carcinoma may provide a clue to the site of origin. A poorly differentiated carcinoma in the upper part of the neck should place the nasopharynx under suspicion for this is the most common silent primary site. Thyroid carcinomas may be very small, and papilliferous adenocarcinoma in a cervical lymph node should suggest the thyroid. With metastases in the submental or submaxillary region the lip should be carefully examined for surgical scars or radiation changes, because not infrequently a patient will withhold a history of a previous lesion successfully treated. On rare occasions a metastatic mass of squamous cell carcinoma will come from a carcinoma arising in a sebaceous cyst of the scalp; the primary lesion may have been removed earlier without realization of its true nature. Adenocarcinoma or scirrhous carcinoma in a node in the medial part of the supraclavicular fossa on the left side

(sentinel node) often develops from carcinoma of the stomach. Supraclavicular metastases on either side, squamous cell carcinoma or adenocarcinoma, may come from carcinoma of the bronchus. Breast carcinomas not infrequently produce supraclavicular and cervical metastases, although axillary or breast involvement will usually be obvious. Even lesions below the diaphragm may have their first clinical manifestation in the neck. Metastases from ovarian carcinomas and even carcinomas of the cervix uteri occur here, as do metastases from renal tumors.

For the radiation therapist knowledge of the primary site of the carcinoma is important. First, it gives him information regarding the probable response of the secondary tumor. Second, if the primary site is not disclosed, it may not be included in the irradiated zone and the patient is deprived of his best chance of cure. Despite the most careful search, a primary tumor may not be found. Since many of these lesions are not operable when seen, irradiation is the common form of treatment.

12

The Breast and Female Genital Tract

CARCINOMA OF THE BREAST

CANCER OF THE breast is the most common malignant neoplasm in the female. It develops in a locality readily accessible to inspection and palpation. By contrast to a deep-seated lesion such as carcinoma of the stomach, the tumor can be felt, if not seen, in the breast even when it is small. Despite this, the death toll in women from breast carcinoma is high.

The results of current methods of treatment are excellent when the carcinoma is localized within the breast, but certain features related to the natural history of the disease often make diagnosis in this stage difficult and even impossible. In a few patients the primary lesion may be so small that it cannot be detected; the presence of the disease is disclosed only by the appearance of axillary or more remote metastases. In others the malignancy may be so aggressive that when the growth becomes apparent clinically, regional and even remote metastases have become established. At variable times after completion of treatment, these reach the clinical horizon and destroy the patient. The carcinoma that appears during pregnancy or in the lactating breast is nearly always aggressive, growing and extending rapidly; few are curable. On the other hand, some mammary carcinomas may be relatively indolent and patients can carry tumors for years before dying. Review of large series of untreated pa-

tients has shown that five years after the onset, about one-fifth will be alive—of course, with disease.

These are not the sole factors that account for diagnosis in the advanced rather than the early stages. Patients' and physicians' actions also enter into the picture. The patient may find a small tumor and through ignorance or fear delay seeking medical advice. The physician may contribute to diagnostic delinquency by engaging in protracted observation rather than acting immediately to establish a diagnosis. Having made the diagnosis, he may do less than might be done for the patient by ill-advised, inadequate and incomplete treatment. The only certain way to establish the diagnosis is by microscopic examination of a specimen of the neoplasm.

Currently an intensive propaganda campaign for early diagnosis is being waged with large-scale publicity to educate women in methods of self-examination and to stimulate physicians to be alert for breast cancer. Estimable as the objectives are, at least the physician must not be so naive as to believe that diagnosis at an early stage can be uniformly achieved. In accord with the biology of breast cancer, a certain group cannot be detected before the disease has passed the scope of curative treatment (no exact data on the size of this group exists but it is estimated to be as high as 40 per cent) and therefore cannot be cured by our present methods. It is doubtful that the utmost vigilance of patient or physician will be of avail in this group. In another group, perhaps 25 per cent of the total, growth is slow and delay in diagnosis may not jeopardize the patient's chance of cure. It is in the intermediate group (? 35 per cent) that efforts at early diagnosis may be rewarded by better therapeutic results.

Until recently one could say dogmatically that the only proper method of treating operable carcinoma of the breast was by complete radical mastectomy. The work of McWhirter has altered the situation. In a large series of unselected patients treated by simple mastectomy followed by vigorous x-ray irradiation of the operated area and its axillary and supraclavicular regions, he has achieved 5 and 10 year survival rates comparable to those obtained by radical surgery. For example, of 742 previously untreated patients seen at the University of Michigan

from 1936 to 1947, the over-all five year survival rate was 40.2 per cent (440 were treated by radical mastectomy). McWhirter obtained a five year survival rate of 41.7 per cent in 1,606 patients. In the past, others have treated breast cancer by simple mastectomy and postoperative irradiation, but the results were inferior to those of the radical operation because a less high standard of irradiation was employed. To obtain results like those of McWhirter, it is essential that the x-ray treatment be more vigorous than has generally been used in the past.

The McWhirter experiment and several other factors have changed the therapeutic outlook on breast cancer from a state of certainty that the radical operation is indisputably the best method of treatment to one of controversy. It is paradoxical that the reported results of the radical operation have been improving over the years but without reflection in improved mortality rates in the disease. This evidently is due to greater care in the selection of cases for operation; Haagensen has carefully defined the criteria of operability. Another point to bear in mind is that an increasing number of workers in the field believe that operation on patients whose disease is beyond the scope of the radical procedure tends to shorten rather than prolong life.

At present, no final answer can be given as to the best therapeutic approach, but it is doubtful that a complete shift from the use of the radical operation in operable cases to treatment of all cases by McWhirter's methods will improve the over-all therapeutic results. Within its scope the radical operation produces excellent results. For example, at the University of Michigan, 197 patients were treated by radical operation and routine microscopic examination of the axillary nodes revealed no metastases; 82.7 per cent were alive five years after operation and 75.6 per cent were alive without evidence of carcinoma. Simple mastectomy will not produce equally good results because it has been shown that microscopic examination of serial sections of the axillary contents may disclose small metastases not found on routine examination in up to 30 per cent of the cases. When routine examination of axillary nodes shows metastases, the results of the operation are much poorer. Of 243 such patients at the University of Michigan, 38.7 per cent were alive at five

years (the five year "clinical cure" rate was 30.5 per cent). However, the survival rate is almost directly inversely proportional to the extent of axillary involvement; with limited axillary involvement the results approach those with no axillary spread.

In the face of such excellent results in cases of no or limited axillary metastatic disease, one should be reluctant to abandon the classic radical mastectomy. The McWhirter results are in part dependent on the facts that the simple mastectomy cures those patients in whom the disease is absolutely limited to the breast and that it avoids an axillary dissection in patients in whom the dissection cannot remove all of the neoplasm—it is in these that the surgical procedure perhaps disseminates the neoplasm and thereby shortens life. An additional group is cured because the high standard of radiotherapy employed eradicates those carcinomas which are radioresponsive. If before therapy one could segregate the patients still within the scope of cure by the radical operation from those beyond this stage and then treat the latter by McWhirter's method, it is probable that the over-all cure rate would be increased. Such discrimination is not possible at present.

It has been the experience at the University of Michigan that postoperative irradiation directed at the axillary pyramid (Plate 96) has not improved the results of radical mastectomy. It is not now employed routinely after the radical operation. When, however, metastatic axillary disease is incompletely removed surgically, irradiation is carried out. Also, if an operative procedure of less scope than the radical mastectomy is performed, postoperative irradiation is used. Preoperative x-ray treatment has largely been abandoned. Inoperable lesions are treated by irradiation, sometimes with simple mastectomy. Inoperability may be determined by extensive local disease in and around the breast, extensive axillary involvement or remote metastases (supraclavicular, intrathoracic, osseous, etc.). Roentgenograms of the chest and spine, including the bony pelvis, should always be made to exclude metastases before operation or irradiation is undertaken.

Frequently irradiation is the only form of treatment carried out in the fulminating types of mammary carcinoma seen during

lactation or pregnancy, and also in the rapidly growing carcinoma that involves the breast diffusely and invades the skin to produce the appearance of lymphangitis or cellulitis—the "in-

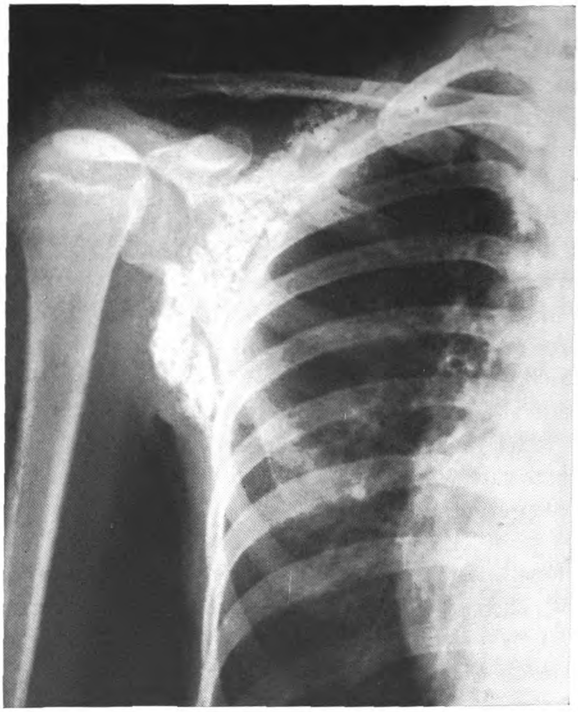


PLATE 96.—Lymph nodes constituting the "axillary pyramid" extend from the armpit into the supraclavicular fossa. Calcification is due to tuberculous lymphadenitis. In postoperative irradiation of the breast this region is vigorously irradiated through multiple fields.

flammatory type." These forms of breast carcinoma are almost never curable; the objective of treatment is palliation.

The treatment of recurrent lesions following operation and of metastases makes up a large part of the work of the radiation therapist in the field of mammary carcinoma. The objective in these cases can rarely, if ever, be cure. What is sought is palliation. Postoperative recurrences in the skin or the chest wall are treated by external x-ray or radium irradiation or even interstitial

radium to produce clinical regression and to prevent the development of fungating, ulcerating tumors. Recurrent neoplastic masses in axillae also may disappear. Supraclavicular lymph node metastases, if unchecked, will obstruct the drainage of the upper extremity and lead to massive brawny swelling; usually the brachial plexus is invaded, followed by severe pain and loss of sensory and motor function in the extremity. Vigorous irradiation, usually external, may postpone such distressing developments indefinitely and, even if they are present, heavy irradiation of the shoulder region and lower neck may be followed in some cases by remarkable alleviation of symptoms. To achieve this, the treatment must be carried to high dosage.

Metastatic skin nodules are a fairly common manifestation that are usually found on the chest wall but may occur elsewhere. When they occur, radiation is administered, the kind of treatment depending on the number of nodules and their location and size. A rather common occurrence is the parasternal or sternal mass; this probably develops on the basis of metastatic involvement of internal mammary lymph nodes. The mass may appear several years after operation. Indeed, a remarkable phenomenon in mammary carcinoma is the long interval that may elapse between operation and the appearance of a metastasis; apparently authentic instances with intervals of 30–40 years have been reported. The parasternal lesion responds readily to radiation treatment.

Extension or metastasis to the remaining breast can take place, and at times this creates a perplexing therapeutic problem. Is the involvement of this breast secondary to that of the removed one, or has a new primary lesion developed? Many times the clinical condition clearly points to secondary involvement; sometimes the pathologist by microscopic study of the neoplasm in the second breast may identify the original tumor. When doubt exists treatment should be the same as for any primary breast cancer; otherwise, treatment will be by radiation methods. If the second breast is occupied by a fungating or ulcerating lesion, or if such a lesion is present in an untreated patient, a simple mastectomy can be done to rid the patient of a distressing condition. Surgery, however, is not essential for this

purpose since irradiation can cause regression of the ulcerated mass and subsequent healing over of the skin. Large lesions of this type, beyond the scope of palliative surgery, have been made to undergo complete clinical regression and healing by radiation treatment (Plate 97).

Metastasis to the skeleton is frequent with cancer of the breast. Since secondary neoplastic deposits in bone may be clinically silent, routine radiography is necessary before either surgery or irradiation is planned for the primary site. The bony pelvis and the spine are the usual sites of metastatic involvement and should be surveyed preoperatively. The skull, ribs and femora as well as other bones may become involved. These lesions produce pain which may be agonizing. One of the greatest benefits that irradiation offers to the patient with advanced breast cancer is the relief of bone pain; in over 80 per cent of the cases significant alleviation can be obtained. Whereas opiates become ineffective after three months or so of use, radiation administered periodically may carry a patient along in relative comfort for one or two years, often longer. A number of patients live for one or more years after the appearance of bone metastases. Sometimes these lesions produce pain before they are visible roentgenographically and treatment may be indicated even though radiographic evidence is lacking. Besides ameliorating pain, irradiation can lead to repair of the defects in bone produced by metastases; fractures at sites weakened by neoplastic destruction can be made to heal.

Metastases to the liver and other abdominal organs are common, but radiation treatment has little value for such lesions. Mediastinal and pulmonary metastases as well as pleural invasion are often seen. Most pulmonary involvement takes place by extension from neoplastic mediastinal nodes through the lymphatics of the lung; in general the results of irradiation are poor. Occasionally pleural effusion resorbs after irradiation of obstructing neoplastic mediastinal nodes.

In addition to the treatment of the metastatic focus itself, radiation can produce palliation by an indirect mechanism. In patients with disseminated involvement who have not passed the menopause, abolition of ovarian function by pelvic irradiation

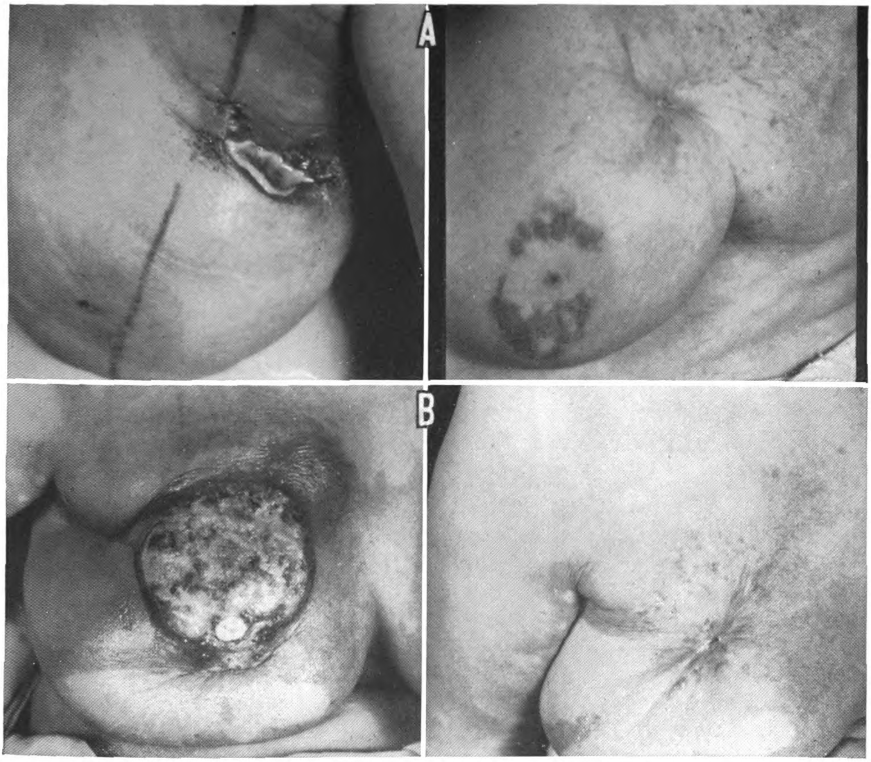


PLATE 97.—Carcinoma of the breast. *A: left,* advanced ulcerative carcinoma of left breast; *right,* complete healing after external irradiation. *B: left,* far-advanced ulcerative carcinoma of right breast (patient sought medical aid because the malodorous discharge made her a social outcast); *right,* regression of mammary tumor with healing of ulceration six months after irradiation.

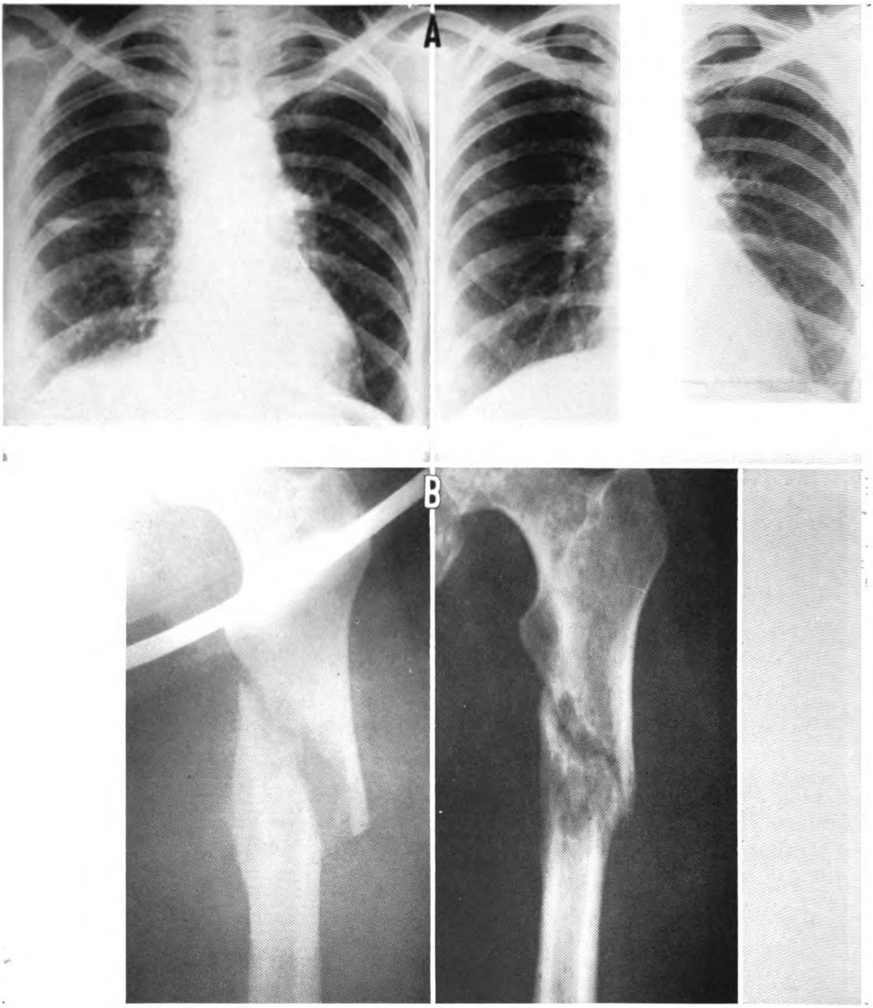


PLATE 98.—Carcinoma of the breast. *A: left,* mediastinal and pulmonary metastases from carcinoma of the breast; *right,* one year later, complete regression of metastases after radiation castration. *B: left,* fracture of femur in an area of metastasis from carcinoma of the breast; *right,* six months later, after x-ray treatment, considerable progress toward union.

is frequently followed by variable degrees of palliation, which in some patients is truly remarkable. Bone pain may cease, defects may heal and even visceral lesions may undergo complete clinical regression (Plate 98, *A*). The improvement is often maintained for one or two years. Despite the fact that abolition of ovarian function may produce these effects in patients with disseminated metastatic disease, there is no firm evidence that castration carried out at the time of radical mastectomy improves the results. However, such a procedure may be advisable to prevent future pregnancy, which is believed to have a deleterious effect. Since adequate irradiation produces a completely functionless and atrophic ovary, surgical castration by laparotomy hardly seems necessary.

The scope of palliative therapy of breast cancer has been enlarged by the introduction of hormonal therapy and surgical ablation of endocrine organs (ovary, adrenal and pituitary). Both androgenic and estrogenic hormones find applicability. Testosterone propionate, usually administered intramuscularly, may produce good relief from pain due to bone metastases and sometimes may also cause regression of soft tissue involvement. Estrogens, indicated only for patients at least five years past the menopause, at times produces remarkable palliative regression of extensive soft tissue disease and may also be effective in bone involvement. When other measures have failed, cortisone has proved beneficial for temporary control of distressing symptoms.

For certain breast cancers which are estrogen dependent (perhaps half of the cases) reduction of estrogen production by ablation of ovarian function (surgical removal of the ovaries or irradiation castration) will be followed by subjective and objective improvement, which in the most favorable instances may last for several years. With adequate dose, ablation of ovarian function by irradiation is as certain as by oophorectomy. The chief advantage of oophorectomy lies in the immediate decrease in estrogen production as compared to a slow reduction following irradiation. When the clinical situation calls for rapid relief of symptoms, the surgical procedure is advantageous.

Bilateral adrenalectomy may also be of palliative value in estrogen-dependent tumors. Some workers perform this opera-

tion at the same time as oophorectomy. Others prefer to castrate first and, when relapse occurs, carry out the adrenalectomy, which may be followed by a second drop in estrogen production. More recently it has been shown that hypophysectomy likewise may produce clinical remissions.

CARCINOMA OF THE FEMALE GENITAL TRACT

Carcinoma of the Cervix Uteri

The carcinoma arising from the epithelium of the cervix uteri, the second most common form of cancer in women, was one of the first cancerous entities for which radiation treatment assumed primary importance. Until the development of a surgical method for radical removal of the pelvic organs in the female, this disease was fatal except in a rare, fortunate person in whom a small lesion was successfully removed by a local operation. At the beginning of the present century Wertheim improved the technic of the radical operation and for several decades many lives were saved by the courage and skill of surgeons using this procedure. Disregarding the mortality risk and the difficulties which followed such extensive pelvic surgery, the chief drawback was the low incidence of operable cases—in more than half the patients seen, it was usually futile to operate because of the extent of the disease. In 1913 in France and in 1915 in the United States, significant groups of cases treated by radium alone were reported and these showed encouraging results. Since then a vast amount of work has been done in developing radiation methods for the treatment of this disease, so that today these methods have relegated surgery to a secondary place.

Carcinoma of the uterine cervix usually develops in the epithelium covering the vaginal face of the cervix and is a squamous cell carcinoma which may vary from a well-differentiated histologic structure to one of such anaplastic morphology that its squamous cell characteristics are unrecognizable. A small proportion of these neoplasms arises in the cervical glands of the endocervix as adenocarcinomas. The primary lesion on the cervix may be typically neoplastic in the form of a fungating

proliferating mass or an infiltrating ulcerating lesion. Often the appearance of the cervix is not characteristic of neoplasm, but any area which appears abnormal, especially when there is a history of abnormal vaginal bleeding, should be subjected to biopsy.

In general this neoplasm tends to remain relatively localized for a considerable time. Metastatic dissemination throughout the body is less than with carcinoma of the breast. Most patients die of recurrent or persistent neoplasm within the pelvis. The most common cause of death is renal failure caused by ureteral obstruction by the neoplasm. From the cervix the carcinoma may extend to the parametrial regions and to the vaginal mucosa. In advanced cases the vaginal involvement can be extensive, reaching the introitus. Metastases to the intrapelvic lymph nodes may occur. One or both sides of the pelvis can become filled with tumor, producing fixation of the uterus. Anteriorly, the bladder may be invaded and with degeneration of the tumor tissue a vesicovaginal fistula may appear. Posteriorly, the rectum may be encroached on, or even invaded, with production of a rectovaginal fistula. Abdominal retroperitoneal lymph nodes at times become the site of metastatic disease. Occasionally clinical evidence of metastases is found in the lungs, skeleton, supraclavicular lymph nodes and other organs.

After the diagnosis is established positively by means of biopsy, certain preliminary steps must be taken before treatment is started. At the time of pelvic examination it does not suffice simply to identify a lesion on the cervix. By inspection of the vagina and the cervix coupled with careful digital examination through the vagina and rectum and bimanual palpation, the extent of the neoplastic involvement is ascertained. Correct assessment of the anatomic extent of the tumor is of considerable importance since this is the most significant factor in determining the prognosis. The rectal examination frequently gives more information than the vaginal examination about the status of the contents of the pelvis and should not be omitted.

In the pretreatment evaluation of carcinoma of the cervix special attention is directed toward the urinary tract. The bladder, ureters and the kidneys, indirectly by ureteral occlusion,

frequently become involved. Invasion of the bladder can be determined by cystoscopic examination, although biopsy of the vesical mucosa may be necessary. The status of the ureters and kidneys can be demonstrated by pyelographic examination; usually the excretory type suffices, but at times the retrograde procedure is advisable. Roentgenograms of the spine and pelvis are desirable to exclude the presence of metastatic disease and are essential when pain is present. Films of the chest are also important.

For surgical treatment the division of the cases into two groups, operable and inoperable, had appeared sufficient, although actually there was a third group consisting of borderline cases variously declared operable or not depending on the diagnostic and technical skill of the individual surgeon. With the development of radiologic methods practically all patients were treated, so it became necessary to classify cases on the basis of the extent of the neoplasm. Allocation to well-defined stages of the disease makes possible sound evaluation of the results of treatment, and these stages, if properly set up in respect to increasing neoplastic involvement, are of great prognostic significance.

In 1929 the Subcommittee on Radiotherapy of Cancer of the Committee on Hygiene of the League of Nations recommended a clinical classification consisting of four stages. Revised in 1937, this classification is widely employed throughout the world.

Stage I. This consists of all carcinomas of the cervix in which the neoplasm is confined to the cervix. This obtains regardless of the extent of involvement of the cervix; no invasion of the vaginal fornices or the parametria must be present.

Stage II. The carcinoma invades one or both parametria but does not reach the pelvic wall; it involves the vaginal mucosa but not the lower third of the vagina.

Stage III. The neoplasm invades one or both parametria to reach the pelvic wall; i.e., the parametrium is involved in its entire length. On rectal examination, the examiner cannot place his finger between the tumor and the pelvic wall. The tumor invades the vaginal wall to involve the lower third of the vagina or isolated metastasis is present in the lower third of the vaginal

mucosa. Also included in this stage are those cases in which isolated metastases are present on the pelvic wall; these are felt on rectal examination as hemispheric masses attached to the pelvic wall posterolaterally.

Stage IV. The neoplasm invades the bladder wall, e.g., positive cystoscopic biopsy evidence or vesicovaginal fistula. There is invasion of the rectovaginal septum, rectovaginal fistula or, on combined rectal and vaginal palpation, the septum is thickened and indurated and the rectal wall is indurated and fixed. The tumor extends beyond the limits of the true pelvis: involvement of the vulva, inguinal or abdominal metastasis, distant metastasis.

In allocating cases to the stages of this classification, the following rules are observed. Staging should be made before treatment is begun. The general condition of the patient does not enter into the staging. When in doubt between two stages, the stage of lesser extent is to be chosen. The presence, in the same case, of two or more factors characterizing a stage does not affect staging. Previously treated lesions should be grouped and considered separately.

Recently a separate stage, stage 0, has been added to designate carcinoma in situ of the cervix. In this entity the cells of the cervical epithelium are so altered as to have the appearance of cancer cells but there is no infiltration into the underlying stroma, and the basement membrane remains intact. Doubt exists regarding the significance of this histologic abnormality. It is thought that in some cases the process may progress to true, invasive cancer of the cervix and that perhaps in other cases it is a spontaneously reversible process. At present, carcinoma in situ of the cervix is not to be considered true cancer of the cervix. Its treatment and prognosis differ from cancer of the cervix.

At the University of Michigan, the League of Nations classification is used but with a different numbering system, stemming from classifications which have been employed in the past. Stage II is called clinical group IV_2 (the subscript number 2 referring to stage II); stage III is clinical group IV_3, and stage IV is clinical group IV_4. Stage I is subdivided further into clinical

group I (very small carcinomas), clinical group II (all other carcinomas still confined to the cervix) and clinical group III (in which questionable parametrial or vaginal mucosal invasion is present or in which, among several examiners, there is disagreement over correct grouping into clinical group II or IV_2).

The radiation treatment of carcinoma of the cervix as practiced by most workers entails the use of both radium and x-ray. Radium was the first to be used effectively and even today remains the basic agent in the sense that in most cases it contributes the greater portion of the radiation dose delivered to the pelvic organs. The role of x-rays is to augment this dose. Of the factors making this lesion suitable for radiation treatment, the most important are the relatively localized nature of the disease in many cases and the high radiation tolerance of the cervix, uterus and upper vagina—the sites in which the radium sources are introduced. The order of sensitivity of the cervical carcinoma is such that severe damage to complete destruction can be produced. The anatomic situation is also favorable in that the bladder and rectum, which are relatively sensitive to radiation effect as compared with the cervix, can be protected in most cases by proper positioning of the radium sources and by increasing the distance between these organs and the radium by means of interposed packs.

Radium, contained in metallic tubes of sufficient wall thickness to absorb at the very least all of the beta rays, is placed within the upper vagina, the cervical canal and the uterine canal. In the uterus two or three tubes, in tandem arrangement, are introduced after gentle dilatation of the cervical canal, so that one tube occupies the cervical canal and the others extend up into the body of the uterus. A number of applicators of various designs are available for this purpose. Two or three radium tubes are also placed in the upper vagina. The most satisfactory arrangement is to have a radium source in each lateral fornix; if the fornices are roomy and not rigid, when the vagina is packed the radium sources come to lie relatively close to the parametria and contribute a large dose to these areas. Thus the cervix, most if not all of the uterus and the parametria can be

vigorously irradiated by cross-firing radiation from the multiple radium foci. If the lateral fornices are shallow or absent, radium tubes are packed into them or against the lateral part of the face of the cervix. In some technics, a third radium tube is often placed against the face of the cervix in the midline. Many different kinds of applicators to house the vaginal radium sources have been designed, but with all of them the radium tubes are placed in the vagina in a vertical position so that the maximum irradiation is directed toward the cervix and parametria and not toward the bladder and rectum.

The type of radium application just described is known as intracavitary. Others have used long radium needles which when inserted about the cervix extend well into each parametrium. However, the results have not equaled those obtained by good intracavitary radium technics.

At the University of Michigan, a tandem source is placed in the uterus for about four days; this is removed and, in a day or two, the vaginal radium sources (one in each fornix) are packed in place and remain from slightly less than four to 5½ days depending on the size of the vagina. The exposure to the radium may range from 7,000 to 10,000 mg.-hr. in 10–12 days. The dose in roentgens may be computed from the position of each radium source and its distance from the points in question. In other radium technics, all the sources are put in at one time for shorter periods but the application is repeated several times at intervals. The use of a large weight of radium for a short time, administering the total dose at one sitting, is being used less often than formerly.

Infrequently is difficulty encountered in eradicating the primary carcinoma of the cervix, for adequate radium technics achieve this end with few exceptions. The failures of radiation treatment more often are due to inability to control the extensions of the neoplasm in the parametria or other pelvic tissues. This results from the fact that the radiation dose, although high in the immediate vicinity of the radium source, decreases rapidly with increasing distance from the source. External x-ray irradiation is used to augment the dose in the parametria and in the tissues extending from these structures to the lateral pelvic walls

in order to increase the total volume of tissue receiving an adequate radiation dose. A fractional high-voltage technic is used, treating daily for several weeks through multiple pelvic fields. The x-ray and the radium treatments are not to be considered separate or competing methods; they are components of the radiation treatment of carcinoma of the cervix. At some clinics x-ray treatment follows the radium application; at others it is used first. At the University of Michigan with few exceptions the x-ray irradiation is carried out first and is followed in several days by the radium application. Preliminary x-ray irradiation serves to decrease the size of large cervical tumors and thus to enhance the ease and efficacy of the radium application. Surgical removal of a protruding cervical tumor is generally condemned. X-rays also seem to diminish the risk of lighting up a chronic or subacute pelvic inflammatory process which sometimes follows large radium doses and accounts for the slight mortality risk with this type of treatment.

The classic method of preliminary external irradiation with x-ray followed by application of multiple sources in the uterus and in the vagina may be impossible to carry out for a variety of reasons. The anatomy of extensive vaginal involvement may make it impossible to make a normal radium application and modifications may be required that result in severe limitation of the radium dosage. On occasion a cervical canal will not be found—this should occur rarely—and the intrauterine application cannot be made. Previous subtotal hysterectomy (carcinoma of the cervical stump) will prevent complete or any intrauterine application; the same situation exists in cases of recurrence in the vagina after hysterectomy. In such instances more intensive external irradiation is administered through six or more fields over a period of 50–60 days; this is followed by the limited radium application or at times by pervaginal x-ray treatment. In some cases no form of internal treatment will be possible and treatment will rest with external irradiation only. These generally are advanced cases, stage III or IV, and the results will be poor, but even with only external irradiation an occasional patient will be salvaged. On the other hand, overwhelming obesity may make external irradiation ineffective and treatment will

be limited to radium only. Also, poor general condition due to causes other than the neoplasm may make it wise to curtail the duration of treatment and radium alone is used.

Following irradiation, the cervical reaction consists at first of progressive erythema and then of membrane formation. At the height of the reaction, three to four weeks after treatment, a necrotic slough covers the cervical face which gradually separates and at the same time heals. About two months after irradiation the reaction has largely or competely subsided. The upper vagina may contract as a result of fibrous tissue formation; adhesive vaginitis may contribute to this decrease in size, and gentle dilatation may be necessary to break up the adhesions. During the phase of acute radiation reaction, bladder (frequency, urgency, etc.) and rectal (diarrhea) symptoms are often present; these can be minimized by proper symptomatic therapy. Reactions occurring months after irradiation may develop in the bladder and rectum owing to scarring and vascular changes. In the bladder the most severe complication is formation of a chronic ulcer which stubbornly resists healing, but this is an infrequent sequel to good radiation technic. Rectal ulceration may occur but will heal under proper treatment; sometimes severe ulceration and stenosis may necessitate colostomy. An inevitable consequence of the radiation treatment in premenopausal patients is total abolition of ovarian function, producing a premature menopause, but this also follows radical surgery since the ovaries are removed.

The results to be expected from competent radiotherapy of previously untreated carcinoma of the cervix follow. For stage I, the five year survival rate should be about 70 per cent; rates exceeding 80 per cent have been reported. For stage II, the five year survival rate should be between 40 and 50 per cent; rates up to 60 per cent are reported. Stage III represents advanced disease; nevertheless, one may anticipate a five year survival rate of 20–30 per cent. It is noteworthy that this advanced stage of carcinoma of the cervix has a better prognosis than carcinoma of the stomach or carcinoma of the bronchus. Only an occasional stage IV case is salvageable; the five year survival rate is less than 10 per cent. With the distribution of

cases usually seen today among the four stages, an over-all five year survival rate of 40–50 per cent of all previously untreated patients may be anticipated. The five year survival rate at the University of Michigan is 49 per cent. For these computations of survival rate, all patients dying before five years are counted as cancer deaths and all patients seen who were previously untreated are included whether completely treated or not treated at all; in other words, these may be considered minimal results.

Surgical treatment of carcinoma of the cervix, consisting of radical removal of the pelvic organs and lymph nodes, has never been completely abandoned. With modern methods of pre- and postoperative care and the use of antibiotics, the operation in stage I and II cases, selected on the basis of the patient's youth, good health and absence of obesity, can be carried out by experienced, skilled surgeons with a low operative mortality rate and can produce good results. The results, however, are no better than those obtained by skilful radiotherapy in unselected case material. This plus the relatively limited applicability of the surgical procedure make it appear that surgery does not add materially to the therapy of this disease. It cannot be too strongly emphasized that a hysterectomy is not an adequate surgical procedure for carcinoma of the cervix.

Carcinoma of the Endometrium

The carcinoma that arises from the endometrium of the uterus is quite different from the carcinoma of the cervix although anatomically they are in close association. Carcinoma of the cervix comprises about 65 per cent of the cancers encountered in the female genital tract and the endometrial carcinoma only about 15 per cent. The latter tends to occur in women past the menopause; the age group of highest incidence is about 10 years older than that in carcinoma of the cervix.

Histologically the endometrial carcinoma is an adenocarcinoma and may vary in degree of differentiation. Infrequently, squamous cell carcinoma is encountered and probably arises from the columnar endometrial cells by metaplasia. Diagnosis is established by microscopic examination of tissue obtained by curettage of the uterus. On the whole the aggressive character

of the malignancy is less marked in the endometrial than in the cervical carcinoma. The tumor tends to be limited to the uterine cavity and, although it infiltrates the myometrium, extension outside of the uterus to the parametria and metastases to the pelvic lymph nodes are relatively late manifestations.

The basic treatment of carcinoma of the endometrium is surgical, consisting of removal of the entire uterus, including the cervix, ovaries and fallopian tubes. In operable cases the results are fairly good, with up to 66 per cent five year survival rates. Radiation methods are being used to an increasing extent in the treatment of this disease. Particularly preoperative irradiation has been used in operable cases in an attempt to improve the results of surgery. For this purpose radium placed within the uterine cavity has been generally used, but at the University of Michigan preoperative x-ray treatment is preferred. In 91 patients treated preoperatively with x-ray followed in six weeks by hysterectomy, the five year survival rate was 90.1 per cent. When operation is not possible because of the patient's poor general condition or extension of the neoplasm beyond the uterus, thorough external x-ray treatment is carried out and followed by radium within the uterus and sometimes the vagina; up to 57 per cent of operable cases so managed resulted in cure. In the advanced cases with extrauterine invasion about one fifth of the patients can be cured.

Carcinoma of the Ovary

The ovary is the site of many diverse types of neoplasms, both benign and malignant, and their classification is difficult because so little is known of the histogenesis of many of them. Of the malignant ovarian tumors the adenocarcinoma is the most common and is usually a papilliferous serous cystadenocarcinoma. Probably most ovarian carcinomas arise on the basis of malignant transformation of benign cysts. In addition to primary carcinoma the ovary not uncommonly is the site of metastatic deposits, the best-known example of which is Krukenberg's tumor, an adenocarcinoma whose primary location is usually the gastrointestinal tract. The ovarian carcinomas are somewhat less common than the endometrial lesions.

As in carcinoma of the uterine body the basic method of treatment is excision, although more often than in the corpus lesion this is not possible. Small ovarian carcinomas usually are symptomless and only the presence of a mass may call attention to the lesion even when it is fairly large. On operation it is not uncommon to find extension beyond the ovary into other pelvic structures as well as disseminated peritoneal implantation; involvement above the level of the umbilicus is frequent. Unless the disease is limited, surgical results are not good.

Radiation treatment does not make up for the deficiencies of surgery in this disease. It is useful but offers less than in carcinomas of the endometrium. Irradiation of the pelvis to fairly high dosage after operation is common practice, particularly if there is reason to suspect that excision was incomplete.

Inoperable cases with disseminated abdominal and peritoneal involvement should always receive radiation treatment, for some will show remarkable regression of the neoplasm with concomitant symptomatic improvement even to a state of apparently normal health. Such favorable degrees of palliation are not the rule, but lesser degrees are relatively common: bulky masses decrease in size, accumulation of ascitic fluid is suppressed or retarded and life may be prolonged.

Preoperative irradiation is not usually practiced because diagnosis without at least an exploratory operation is seldom possible. (Large masses and even ascites may be due to benign tumors, and histologic examination is necessary to establish the diagnosis of carcinoma.) In some advanced cases an interweaving of radiation and surgical treatment may prolong life under comfortable conditions. On laparotomy a large inoperable mass or masses may be found and only a part or perhaps none of the neoplasm can be removed. The abdomen is closed and after the wound is healed vigorous irradiation is carried out. This may result in a considerable decrease in the bulk of the tumor so that some months later much or most of it can be removed. Should the tumor begin to grow again, further radiation treatment may be given and even a second operation may be of value. Patients have been carried for many years by repeated courses of irradiation and operation.

Of 214 patients seen since 1931 at the University of Michigan, 20.6 per cent were alive after five years. In the small number grossly limited to an ovary, the five year survival rate was 57.8 per cent. When resectable extension was present, the rate dropped to 38.8 per cent and when there was surgically unremovable involvement beyond the ovary the rate was 18.6 per cent. Recurrence of tumor after five years was quite frequent.

In ovarian carcinomatosis of the peritoneal surface with ascites, instillation of colloidal radioactive gold (Au^{198}) into the peritoneal cavity has produced some depression and even suppression of the ascitic fluid formation in a third to half of the cases. Such an effect is of palliative value in cases of distress caused by ascites.

Other Neoplasms of the Female Genital Tract

The carcinomas of the cervix, uterine corpus and ovary constitute about 90 per cent of all malignant neoplasms encountered in the female genital tract. About half of the remaining lesions are found in the vulva and the vagina, the frequency of vulvar carcinoma being about twice that of vaginal carcinoma. Carcinoma of the vulva is a surgical problem and the role of irradiation is minor. Complete vulvectomy is the best procedure and is often combined with bilateral dissection of the inguinal lymph nodes. It is possible to eradicate a vulvar carcinoma by radiation methods (interstitial and surface radium treatment as well as x-ray irradiation) but the tissues do not tolerate such treatment too well. It is important to remember that these carcinomas often arise on the basis of leukoplakic changes in the vulvar skin. Since these changes may be widespread, local destruction of a carcinoma may be carried out successfully only to have another lesion develop nearby. In advanced inoperable tumors fungating masses often have been reduced in size, making the patient more comfortable.

Carcinomas of the vagina usually are radiation problems, for adequate excision is frequently not feasible. The technics of radiation treatment have varied considerably. In lesions of the upper vagina, external irradiation is combined with vaginal radium sources such as those used in carcinoma of the cervix.

In lower vaginal lesions and in diffuse lesions, radium sources arranged axially in the vagina are effective. Interstitial insertion of radium needles may be suitable in some cases.

Among 28 patients treated by radiation methods from 1935 to 1952, the five year rate of survival without evidence of neoplasm was 35.7 per cent.

A lesion infrequently found is the carcinoma arising in the mucosa of the female urethra. As in the vagina, excision is usually not feasible, and interstitial irradiation with needles introduced parallel to the axis of the urethra is the common method of treatment. Sometimes a radium capsule is maintained in the urethra itself. It has been demonstrated that small urethral carcinomas may be cured by external irradiation only.

An interesting but exceedingly rare lesion is the chorioepithelioma which follows hydatidiform moles, full-term pregnancies and abortions. It usually arises in the uterus and is one of the most malignant lesions of the female genital tract. Disseminated metastases involving lungs, liver, brain and other organs occur early. In some cases remarkable regressions have followed irradiation. This is one tumor of which authentic instances of spontaneous regression have been recorded.

Sarcoma of the uterus is uncommon and usually is associated with a pre-existing leiomyoma. The treatment is surgical although irradiation often is tried in advanced cases. Still rarer are sarcomas of the vagina, which may occur early in life, even in infancy. Irradiation causes tumor regression in some, but permanent eradication probably has never been achieved.

Clinical Application of Radiation Castration

The ovary is sensitive to radiation and moderate doses can permanently abolish its function. This finds clinical application in several circumstances. In carcinoma of the breast radiation castration is often of palliative value, producing symptomatic as well as objective improvement. In several gynecologic conditions it has an important therapeutic role and is frequently used. Abnormal uterine bleeding is common in women at or near the menopause and anemia varying from mild to severe degrees may develop. Ovarian irradiation results in cessation of ovarian func-

tion; bleeding ceases and the menopause takes place or is completed. This amounts simply to an acceleration of the normal course of events.

Radiation castration may be performed by external x-ray or intracavitary radium irradiation. The quantity of radiation in the ovary required to produce permanent castration has been variously estimated to be from 300 to over 600 r. With external irradiation a dose at the ovary of at least 625 r has been used at the University of Michigan with rare failure of production of total castration occurring in young adults. More recently a dose of 1,100–1,200 r has been used routinely. With radium in the uterine cavity the dose also varies considerably from less than 1,000 mg.-hr. to 2,000 mg.-hr. With either technic the patient sometimes has one or two menstrual periods after the treatment before amenorrhea appears.

Diagnosis is very important in cases of uterine bleeding because the possibility of carcinoma of the uterus, either cervix or corpus, must be excluded before radiation treatment is given. The amount of radiation administered to abolish ovarian function is not sufficient to eradicate these neoplasms. To exclude carcinoma of the corpus, curettage of the uterus is necessary and is done before the radiation is administered. Obviously, other diseases which may produce uterine bleeding such as leukemia and purpura must also be ruled out.

Fibroid tumors of the uterus often decrease in size after radiation castration and this becomes the best method of treatment in some patients. Irradiation is usually considered less desirable than surgery in patients with large, calcified, degenerating or submucous fibroids and also in young women. In cases of doubtful diagnosis an exploratory laparotomy is indicated, for an ovarian carcinoma can simulate myoma of the uterus.

Endometriosis, which may be described briefly as tissue having the characteristic histologic and functional attributes of the endometrium, is another condition in which radiation castration is of clinical value. Endometriosis may occur in any organ or tissue in the pelvic cavity and sometimes is found outside the pelvis. It may form masses clinically indistinguishable from neoplasm. Characteristically, there is pain associated with the

menstrual periods; hemorrhage may also occur. Irradiation of the ovaries abolishes the cyclic functional changes which account for most of the symptomatology of endometriosis. Regression of masses of this tissue may take place but often is slow. If the patient is young, the condition operable and preservation of ovarian function desired, surgery is indicated. Large masses may require surgical removal if reduction in bulk is an immediate clinical necessity. Radiation castration is not immediately followed by disappearance of endometriosis, but is followed by cessation of functional activity.

By the administration of a smaller dose, temporary amenorrhea can be produced. This has been done in young women with uterine bleeding not due to neoplastic disease in whom other methods of treatment have failed to bring about normal menses. Occasionally the bleeding is excessive to the point of threatening life and a choice between radiation castration, temporary or permanent, and hysterectomy may become necessary. After hysterectomy the patient is not a castrate but is unable to bear children. With permanent radiation castration the patient is unable to have offspring and is a castrate. With temporary castration the bleeding stops and, after a period of amenorrhea, menses which may now be normal become established and reproduction is again possible. The last procedure appears to be the most desirable, but two objections to it must be considered. Although as a rule it is more difficult permanently to castrate a young female than one near the menopause, occasionally the small dose designed to produce temporary amenorrhea may result in permanent and total castration. The second objection is related to the known ability of radiation to produce mutations when germ plasm is exposed to it. On the basis of current knowledge one must assume that this takes place in the human being and that genetic alteration may follow ovarian irradiation. Dismissal of any possible importance of such a phenomenon on the basis that the first generation of offspring shows no abnormalities is erroneous; the mutations are recessive and cannot become manifest in the first generation. Ovarian irradiation which may be followed by pregnancy is not to be undertaken lightly.

13

Male Genitalia and Urinary Tract

RADIATION THERAPY finds application in a number of the malignant neoplasms of the urinary tract and of the male genitalia. The scope and importance of irradiation vary with the different neoplasms and the stages of the disease. In most conditions the best results are obtained by various combinations of surgical and radiation methods.

Malignant Tumors of the Testis

Malignant neoplasms of the testis are seen chiefly in young men. These tumors are teratomatous, although frequently one type of tissue is present almost to the exclusion of the others. Many of these neoplasms exhibit a markedly aggressive malignant character metastasizing early and widely. The results of treatment have been poor, but have improved in recent years. The prognosis for some of these tumors can be excellent.

Classification of the testicular neoplasms has proved to be difficult and a variety of classifications have been offered. Seminomas, which are common, constitute one group that is of great interest to the radiation therapist. The adult teratomas are slow growing and are late to metastasize. Chorioepitheliomas are highly malignant, metastasize early and are almost never cured by any form of treatment; these tumors occur infrequently (1–2 per cent). Teratocarcinomas form a major group. Associated with some of the testicular tumors is an abnormal urinary excre-

tion of gonadotrophic hormone. This phenomenon may be of diagnostic value and of some aid in the determination of recurrences and metastases but it has not measured up to the initial hopes in these directions. Metastasis appears first in the retroperitoneal lymph nodes. The nodes of the mediastinum and supraclavicular fossae become involved; pulmonary metastases are common.

A considerable proportion of testicular tumors have moderate to high degrees of radioresponsiveness and advantage is taken of this fact in laying out a treatment program. Simple orchiectomy gives poor results, except in adult teratomas, because frequently the neoplasm has already metastasized to the retroperitoneal nodes even though such involvement is not demonstrable. More radical operations have been devised which include dissection of the retroperitoneal nodes; these have been performed more frequently in recent years for neoplasms other than the seminomas. In cases without demonstrable metastases simple orchiectomy is followed by vigorous irradiation of the retroperitoneal lymph nodes except for the adult teratomas.

Seminomas have the best prognosis; when clinically confined to the testis and treated by orchiectomy and postoperative irradiation, five year survival rates as high as 80 per cent have been reported. Even when retroperitoneal metastases are present, cure is obtainable in a fair proportion of cases. Chorioepitheliomas are usually disseminated when seen and are fatal despite treatment. In the other tumors, the results will be variable, depending on the radioresponsiveness and the possibility of removing involved nodes if retroperitoneal lymph node dissection is done.

PLATE 99.—*A: left,* multiple pulmonary metastases from malignant teratoma of testis; *right,* seven months later, complete disappearance of metastases after irradiation. *B: left,* far-advanced carcinoma of penis with fungating inguinal lymph node metastases; *right,* marked regression after irradiation for palliation. *C: left,* Wilms' tumor forming large mass in left side of abdomen; left kidney deformed and displaced downward; *right,* 15 days later, after daily x-ray treatment, marked decrease in size of abdominal mass with less deformity of kidney and partial return to normal renal position. The irradiation was a preoperative procedure.→

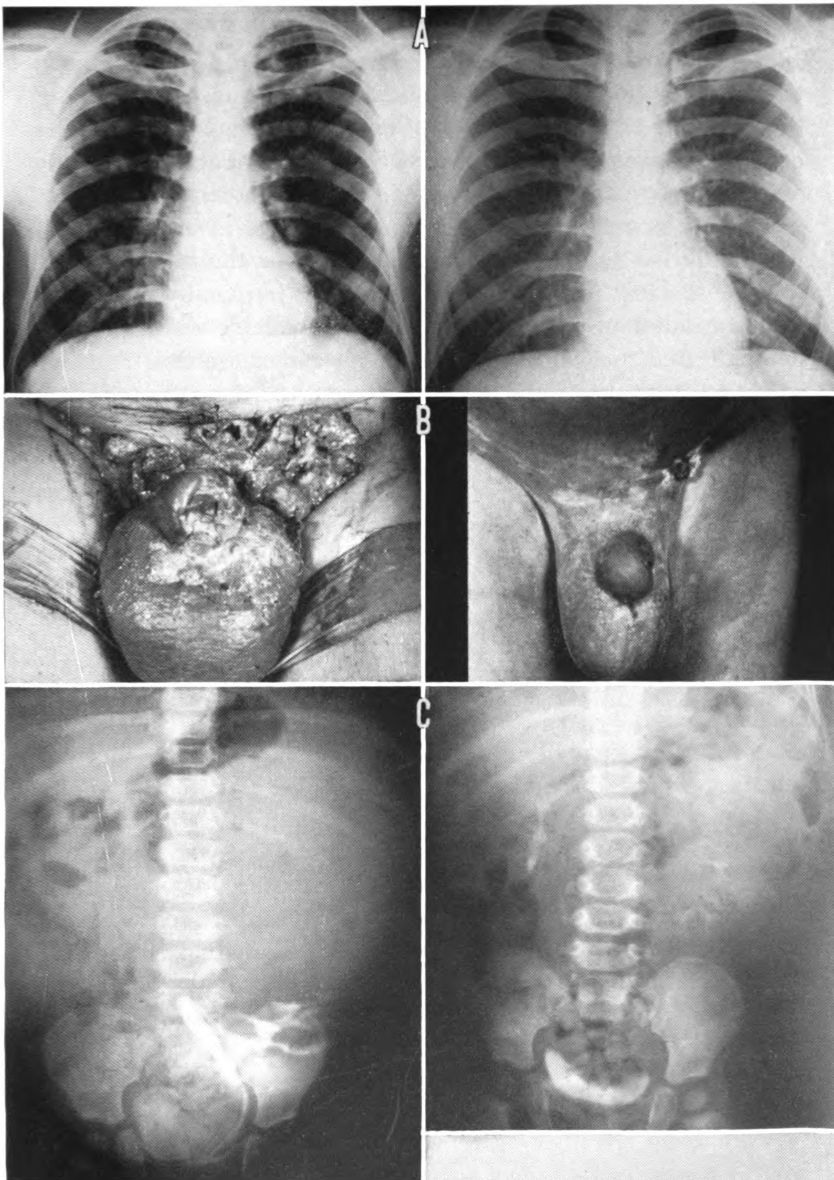


PLATE 99

Carcinoma of the Prostate

Much effort has been expended in devising radiation methods to attack carcinoma of the prostate gland because so many of these lesions when first seen are beyond the scope of complete excision. However, neither external radiation treatment nor any of the ingenious technics of interstitial irradiation which were developed have given satisfactory results. The primary role of irradiation has been to obtain palliation. For the relief of pain due to skeletal metastases, which occur frequently with this lesion, irradiation was the best method available until Huggins demonstrated the value of orchiectomy and stilbestrol. Remarkable effects can be obtained by removing or depressing androgenic activity, and ordinarily irradiation is used only after these methods have been tried and have failed. Recently, renewed attempts at treatment of carcinoma of the prostate by interstitial irradiation have been made with radioactive gold (Au^{198}) in colloidal solution. Some promising initial results have been obtained but more time is required for evaluation of the method.

Carcinoma of the Penis

Carcinoma of the penis is a cornifying squamous cell carcinoma similar to such lesions arising elsewhere in the skin. It develops on or near the glans. The treatment is usually surgical, but the primary lesion may also be destroyed by radiation methods. X-rays, surface application of radium and interstitial irradiation have been used by various workers. However, the penile tissues are not overly tolerant of the necessary doses and the irradiated area may be sensitive and may subsequently break down. Cure of penile cancer depends on elimination of inguinal node mestastases, which occur frequently. The results of irradiation of such metastases are poor; occasionally advanced lesions which have ulcerated are temporarily benefited.

Carcinoma of the Bladder

Papillomas, papillary carcinomas and infiltrating carcinomas comprise most of the tumors of the urinary bladder. Many if not all of the papillomas are precancerous lesions. Unless biopsy

includes the base of the lesion, the site where infiltration first occurs, a papillary carcinoma may be misdiagnosed as a benign papilloma. The methods, both surgical and radiation, available for attack on bladder tumors are multiple and varied but the results of treatment are not too satisfactory, largely because of the advanced extent of the disease in many patients.

The surgical methods consist of transurethral fulguration, fulguration after suprapubic incision and opening of the bladder, partial resection of the bladder wall and total cystectomy with transplantation of the ureters. The radiation methods include: transurethral implantation of radon seeds; opening of the bladder through a suprapubic approach and insertion of radon seeds or radium needles into the tumor, or even application of x-rays by means of a special type of low-voltage x-ray tube, and external irradiation.

Unless the lesion is large the suprapubic approach with adequate exposure of the tumor site is preferred. Limited lesions of the dome of the bladder are removed by partial resection of the vesical wall, but those of the trigone and its vicinity, which make up most of the vesical tumors, cannot be so treated without sacrifice of the ureters or urethra. These may be treated by fulguration or interstitial irradiation. Either radon seeds or radium needles may be inserted into the base of the tumor; the former may be left in place permanently, the latter are removed through the suprapubic wound after an adequate dose has been delivered. If the lesion is projecting or pedunculated, it can be removed surgically down to its base before the radium is introduced.

With more advanced lesions, total cystectomy is sometimes possible, but this major procedure is used infrequently because the mortality rate is fairly high and the results are not good. External irradiation concentrating the radiation in the bladder by directing the beam through multiple external fields is used for palliation; in some cases distressing symptoms are relieved for significant periods. Better tumor regressions are reported with high doses of high-energy radiation (x-rays generated at one to four million volts or cobalt-60 radiation), using multiple

converging fixed beams or rotational technics. Apparent cure has been obtained in an occasional infiltrative tumor.

Hypernephroma

In the treatment of hypernephroma, the most common of the malignant renal tumors, the part played by radiation methods is secondary; total removal which involves nephrectomy not only is the treatment of choice but offers the only hope of cure. Good results are obtained when the lesion has not extended beyond the kidney. Frequently the size can be reduced by vigorous irradiation—sometimes only slightly, occasionally very considerably. Because of this some workers have used radiation therapy preoperatively in lesions of doubtful operability. In all cases in which surgical removal is incomplete, fractional external irradiation to a high total dose is indicated. The only treatment available for pulmonary, osseous and other metastases is some form of irradiation and, if moderately large doses are used, satisfactory palliation may be obtained. The carcinoma which arises from the renal pelvis is less responsive to radiation than the hypernephroma.

Wilms' Tumor and Neuroblastoma

In children the common renal tumor is Wilms' tumor. It usually grows rapidly and most patients present a large mass when first seen. A characteristic feature of this lesion is its responsiveness to radiation treatment. With moderate doses large masses decrease rapidly in size. Surgical removal of the involved kidney has been the usual method of treatment combined with either pre- or postoperative external irradiation. The results of treatment reported in the literature in the past have been consistently poor; in more recent years, the results have been more favorable (25–33 per cent five year survival). Our results fall within this range. The treatment consisted of both surgery and irradiation in most of our cases, but one patient who was treated by radiation alone was alive and well almost 10 years later. Clinically, Wilms' tumor is sometimes confused with neuroblastoma arising in the adrenal gland. The latter also may produce a large

abdominal mass but more often the abdominal tumor is small. This lesion metastasizes early, involving the skeleton as well as viscera, and frequently the metastases dominate the clinical picture. The neuroblastoma is radiosensitive and radiocurable, but few cases are seen without disseminated metastatic disease that renders cure impossible. Cure has been reported when the metastatic involvement was limited to the liver.

14

Lymphoblastomas and Leukemias

IN THE DISEASES of the lymphoid tissue—the lymphoblastomas—and those of the blood cell-forming tissues—the leukemias—irradiation is the predominant means by which the manifestations can be controlled. The word controlled is used advisedly since, with rare exceptions, such therapy does not result in cure. The objective is to keep the patient in as good a state of health as possible for a maximal period. Dramatic regression of large tumors can be brought about. Ailing, weakened individuals may regain their original vigor and sense of well-being following irradiation. Pain, cough and many other symptoms may be completely alleviated. But sooner or later the inexorable progress of the disease leads to a terminal stage in which radiation treatment is of no value.

LYMPHOBLASTOMAS

The lymphoblastomas consist of a group of diseases of lymph nodes and lymphoid tissue which are generally considered to be neoplastic. On a histologic basis certain varieties can often be segregated and classified, but clinical differentiation is frequently difficult. The most common types are Hodgkin's disease and lymphosarcoma; less common are the reticulum cell sarcoma and the entity called giant follicular lymphoblastoma which is considered an early stage of the disease. Since there are no sharp divisions between the various types, exact classifi-

cation is not possible in many cases and the general term lymphoblastoma suffices.

Clinically the manifestations are protean. The classic picture of Hodgkin's disease—unilateral or bilateral cervical gland enlargement—may be seen and a diagnosis readily established by biopsy of one of the nodes. On the other hand, this disease or any of the lymphoblastomas may present extremely difficult diagnostic problems in patients exhibiting no peripheral or mediastinal adenopathy or palpable abdominal masses, and it may be necessary to do an exploratory operation before the diagnosis can be determined. A patient may be asymptomatic and seek medical aid solely because of enlarged lymph nodes; at the other extreme is the desperately ill patient with high fever, marked toxicity and prostration. A large mediastinal tumor may cause respiratory embarrassment and threaten suffocation. Virtually any organ may be involved and the symptoms and physical findings can completely simulate those of other diseases.

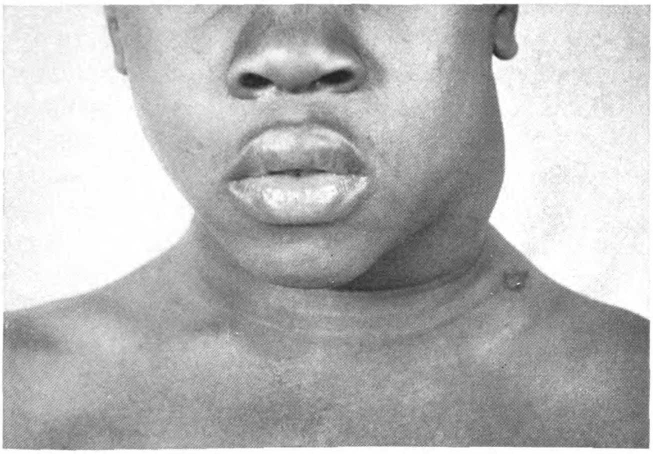


PLATE 100.—Hodgkin's disease. Enlargement of left cervical nodes at age 8 years as shown here. Following irradiation, the patient was free of evidence of the disease for 10 years. The patient, still alive at age 24½ years, required occasional radiation treatment.

Mediastinal involvement, seen on the roentgenogram usually

as a mass in the anterior superior mediastinal space, is common and sometimes is clinically silent. Patients are seen in whom the mediastinal tumor is the only finding; careful search discloses no peripheral lymph nodes which merit biopsy, or a removed node may show only chronic lymphadenitis. The peripheral blood may be normal. Other diagnostic procedures such as bronchoscopy may give no clue to the nature of the process in the mediastinum. Before recourse is had to exploratory thoracotomy, irradiation should be utilized as a diagnostic measure. If the mass completely or markedly regresses with a moderate dose of radiation, a presumptive diagnosis of lymphoblastoma may be considered established, and any surgical procedure is contraindicated. The failure of a lymphoblastoma to respond to such a dose is extremely rare and only seldom does a non-lymphoblastomatous primary tumor of the mediastinal structures simulate lymphoblastoma in its reaction to radiation.

Radiation treatment of the lymphoblastomas is almost universally restricted to external irradiation. The sites that are treated vary according to the areas involved: peripheral lymph node areas, mediastinum, abdomen, retroperitoneal region, skeleton and so on. No formulas exist in respect to sites, doses and periodicity of treatment. The underlying principle of radiation therapy is to keep the patient free from subjective and objective evidence of the disease for the longest possible period. To achieve this, treatment will be given when obvious or presumptive evidence of disease appears; the doses used will be large enough to produce essentially complete, initial regression but not so large as to make re-irradiation at a later date impossible. Attempts to eradicate the disease at one site with large doses such as those used in carcinomas are generally inadvisable. Irradiation of all the lymph node-bearing areas of the body, whether or not they demonstrate disease, is not considered good practice, since such widespread distribution of radiation may in itself be deleterious and impair the patient's health.

Lymphoblastoma arises by transformation of any of the lymph nodes or foci of lymphoid tissue into this neoplastic disease; one cannot speak of a primary tumor at one site and con-

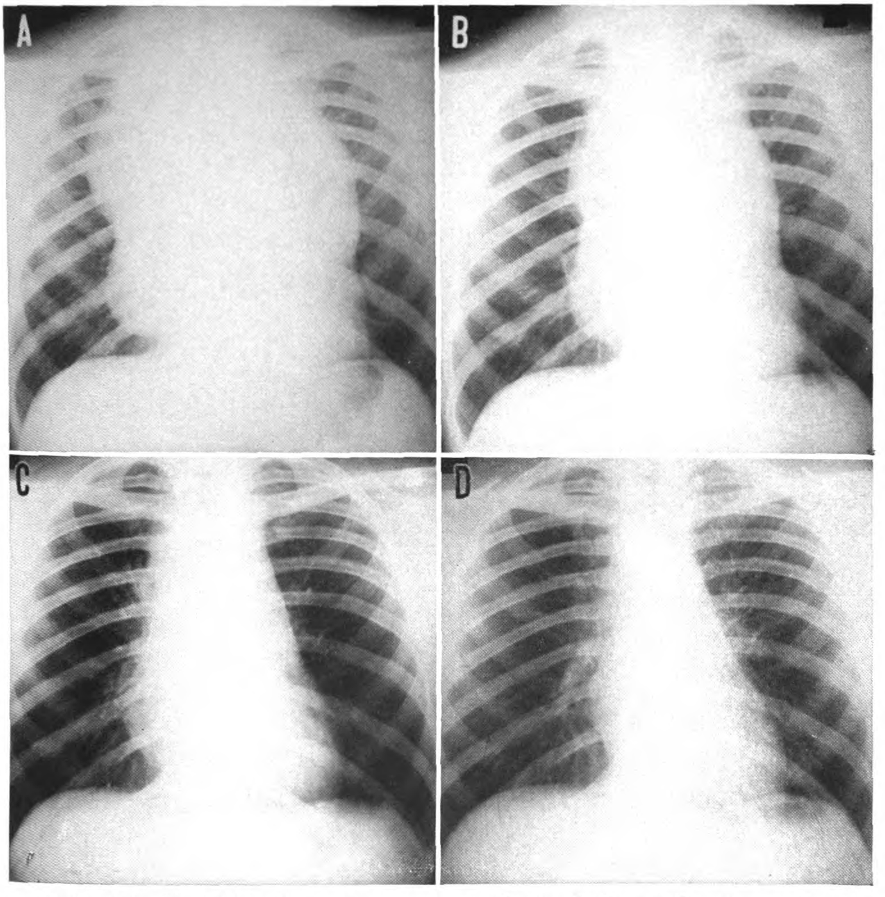


PLATE 101.—Hodgkin's disease. *A*, massive mediastinal adenopathy; *B*, considerable decrease in size 10 days after administration of moderate radiation dose; *C*, marked regression two months later (no treatment in interim). More treatment was given at this time. *D*, seven months later, slight residual adenopathy. The patient died five years after the roentgenogram shown in *A* was made.

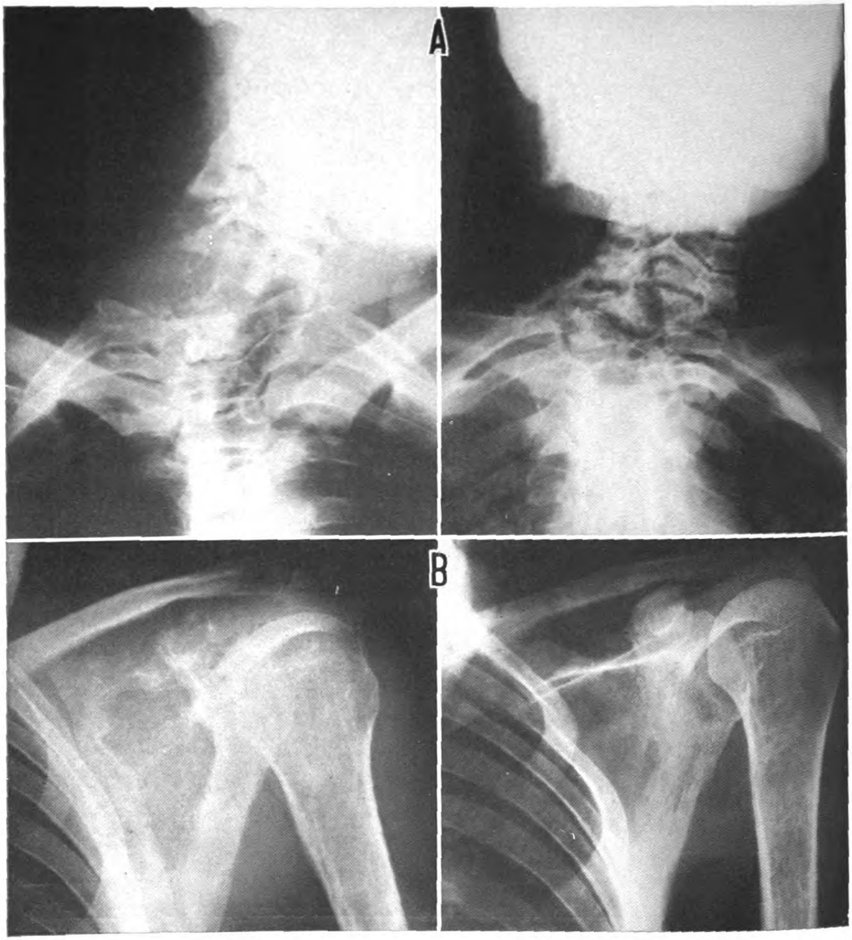


PLATE 102.—Hodgkin's disease. A: *left,* extensive destruction of lower part of cervical spine; *right,* considerable osseous repair followed irradiation leaving, however, residual deformity. B: *left,* destruction of upper part of left scapula. Essentially complete repair followed irradiation. *Right,* appearance 10 years after treatment.

sider other areas of involvement metastatic. Even though the disease is wiped out at the site of first appearance by heavy doses of radiation it will appear elsewhere after a variable interval. Some particular focus critically located in relation to some organ or physiologic function may cause death; otherwise, a gradual generalization of the process will take place by transformation of all or most of the lymphoid tissue. Infiltration of the neoplastic cells into adjacent regions will occur. Basically, radiation treatment fails to cure because of the multicentric origin of the neoplasm. After repeated treatment and after generalization has taken place, the response to further irradiation, at least as far as symptomatic improvement is concerned, is poor or absent. In the case of lymphosarcoma there are exceptions to the course of events just described; localized tumors (e.g., tonsil, stomach, intestine, etc.) may be eradicated either by surgical removal or by vigorous irradiation without the subsequent appearance of the neoplasm elsewhere in the body.

The average length of life following the diagnosis of lymphoblastoma appears to be between two and three years. But the average as a statistic, as is frequently true, gives a false picture because it does not indicate the variation of the items from which it is computed. Variation in the length of life and also in the character of the clinical course is marked in the lymphoblastomas. In some patients the disease has a rapid course and despite irradiation may be fatal in a few months; in these, the clinical picture is that of an acute process often with fever and high toxicity. At the other extreme are patients who present localized nodal involvement which regresses under treatment, to be followed by an interval of months and even years before new nodes appear; these patients may live for years in good health as a result of intermittent irradiation carried out whenever manifestations of the disease appear. For Hodgkin's disease figures ranging as high as 30 per cent five year survivors are to be found in the literature. Patients do survive over 10 years and we, as well as others, have seen a patient alive and doing well clinically as long as 25 years after the diagnosis was established. Such patients, however, cannot be considered cured. As a group, those with lymphosarcomas appear to do less well than those with

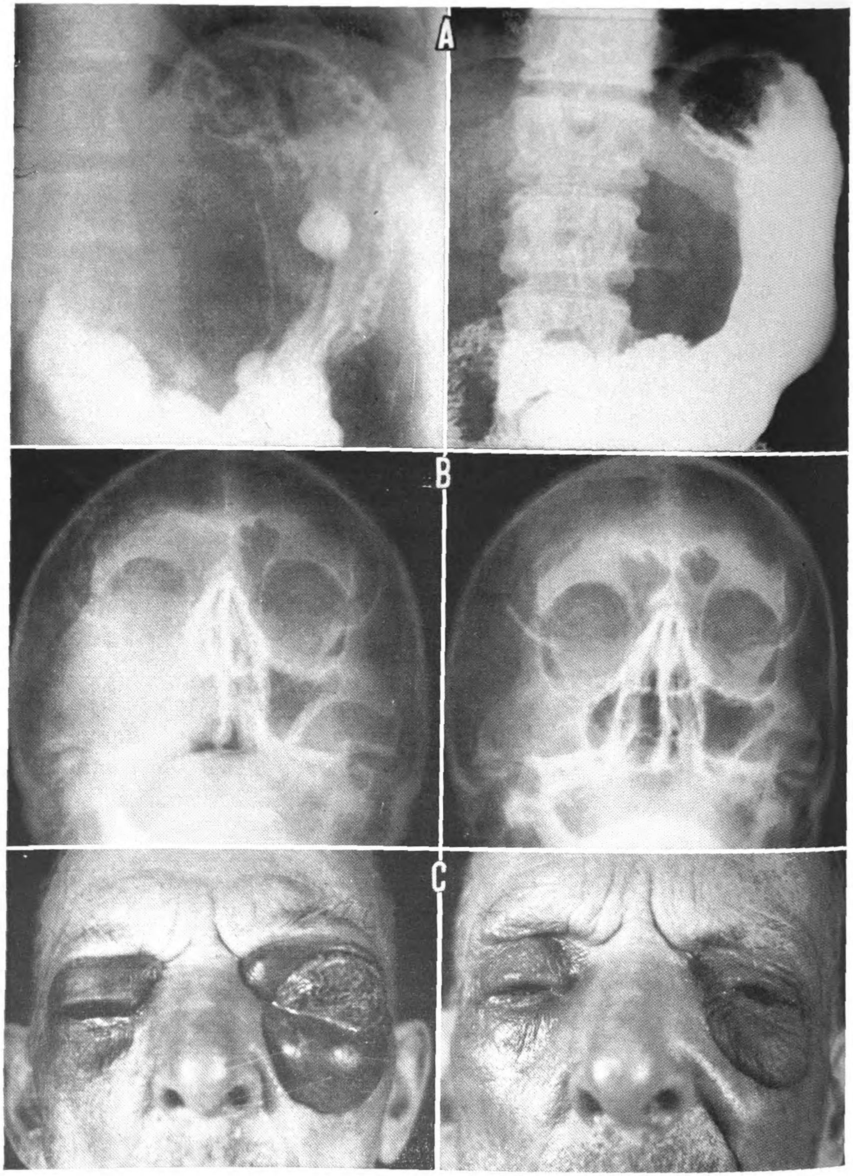


PLATE 103

Hodgkin's disease. It should be clearly understood that fundamentally the long survivals are due to the chronicity of the clinical course; however, without irradiation to check manifestations that threaten life, existence would be shortened and symptomatic distress would be much greater.

In recent years the therapeutic armamentarium against the lymphoblastomas has been enlarged by the development of chemical agents (nitrogen mustard, triethylenamine and others) that affect this type of neoplasm and can cause regression of lymphomatous tissue and relieve symptoms. Although in general their effects tend to be shorter-lived than those of proper irradiation, considerable palliation can be achieved when irradiation is unsuitable because of overwhelming generalization of the disease. When appropriately applicable, irradiation is considered superior in results to chemotherapy.

Leukemias

The leukemias are classified according to the types of abnormal white cells in the blood. The most common types are the granulocytic (myelogenous) and the lymphatic. Clinically, in the former splenomegaly dominates the picture and in the latter lymph node enlargement is usually the outstanding feature. The objective of irradiation is symptomatic control, not the maintenance of a normal white cell count. Ease of fatigue, weakness, pressure symptoms from an enlarged spleen, enlarging lymph nodes and so on, rather than an elevated white cell count, comprise the indications for radiation treatment; treatment while the patient is asymptomatic is justified with a *rising* white count. Following treatment the white count will fall, the spleen will decrease in size, lymph nodes will regress, the patient will become stronger and hemoglobin values will increase. For a

---

←PLATE 103.—Lymphoblastoma. *A: left,* two lymphoblastomatous ulcers of stomach; *right,* ulcers disappeared after external irradiation. *B: left,* lymphoblastoma involving right antrum with destruction of bone, extending into right side of nose and palate and producing subcutaneous mass in right cheek; *right,* complete regression with bone repair after moderate external radiation dose. *C: left,* lymphoblastoma of eyelids and orbits; *right,* 11 days later, after irradiation.

variable period the patient will feel well, but eventually the symptoms will recur, perhaps very gradually, and re-treatment is necessary. This cycle of events will be repeated perhaps for several years, but the remissions will become shorter and the palliative value of irradiation will become less and less. Blood transfusions constitute an important adjuvant in the treatment of the leukemias.

Not all leukemias respond equally well to radiation treatment. In the acute leukemias such treatment is of little or no value. The results are less satisfactory in leukemias with high percentages of immature white cells than in those in which mature forms dominate the blood picture. In general the results are somewhat better in the granulocytic than in the lymphatic type. The monocytic leukemias tend to respond poorly.

The technic of irradiation in these diseases has been quite variable. In granulocytic leukemia irradiation of the spleen produces good results and is the usual procedure. In lymphatic leukemia the enlarged nodes are treated but the spleen also may be included in the irradiation program. The doses are relatively small and are controlled by close check on the reaction of the white cell count. Treatment may be given daily or at longer intervals. In addition to irradiation of local segments of the body, it is possible to treat the entire body at once by using target-skin distances of 1½–2 meters. For treatment of granulocytic leukemia, this has been our preferred method. With this technic at each exposure small doses of the order of 10–30 r are used in contrast with doses of 100–300 r which are usual in splenic or lymph node irradiation. Actually the discrepancy in dosage is not as great as it appears and the equivalence is roughly indicated by multiplying the dose by the volume of irradiated tissue. Three hundred to 400 r delivered to the entire body at one sitting will seriously damage the hemopoietic system and may be lethal.

Total body irradiation is particularly effective in controlling the symptoms of *polycythemia vera.* The red cell count and the hemoglobin content can be reduced to normal values and so maintained for long periods. This effect is due to depression of the rate of red cell formation rather than to destruction of cells

already formed. Irradiation should not be carried to the point of production of leukopenia.

In the treatment of leukemias and polycythemia vera radioactive phosphorus (P^{32}) has been introduced. Phosphorus manifests some predilection for lymphoid and bone marrow tissue and thus the radioactive atoms reach a site advantageous for irradiation in diseases of these tissues. In effect this is a type of total body irradiation. It appears to be an alternate rather than better radiation treatment of these diseases, although some workers favor it highly for polycythemia vera.

15

Bone; Chest; Gastrointestinal Tract; Central Nervous System

BONE

TUMORS OCCURRING in bone have always been of interest to the radiologist for the roentgenologic depiction of such lesions constitutes the only important means of studying their gross pathologic anatomy in the living patient. Diagnostic radiology has made major contributions to our knowledge in this field. The treatment of these conditions has been and still is dominated by surgery. Except for the giant cell tumor, radiation treatment has no value in the benign osseous neoplasms. In the primary malignant tumors, however, irradiation does find application. Although they are relatively rare, the malignant tumors have been the focal point of interest because of the challenge they present to our current methods of treatment. Some of these tumors are among the most dangerous that occur in man. Although surgical methods cure some, the results generally are poor. Strenuous efforts have been made to improve this situation by incorporating irradiation in the treatment program but such attempts have not been very successful. Although most are not radioresponsive lesions, exceptions occur and it is in these that radiation therapy makes its contribution. Of course, in metastic lesions in bone, irradiation is the principal means of obtaining relief of symptoms.

GIANT CELL TUMOR. Although the benign giant cell tumor has been classified as a neoplasm, many believe that it is a regenerative or reparative process rather than true neoplasm. This tumor is rare; most commonly it is located in long bones in the metaphysis, but flat bones and the vertebrae may also be involved. The prognosis is good. Surgical treatment is conservative and consists of curettage usually with chemical cautery. Radiation therapy also is conservative in the sense that only moderate doses are necessary to induce healing. Since good results can be obtained by either method, decision as to which to use is made on other grounds, among which are the location (this determines accessibility to surgery), economic factors (healing following irradiation is slow) and the availability of expert surgical or radiation practitioners. Agreement is fairly general that the combined use of surgery and irradiation is undesirable. Tumors recurring after surgery may be irradiated, and the reverse procedure also applies.

The postirradiation phenomena seen in this lesion are unique, interesting and important to understand in order to avoid serious errors in management. Several weeks after irradiation roentgenograms will show increased decalcification associated with some increase in the size of the tumor. Together these features suggest progression of the lesion and in the past this erroneous interpretation led to surgical intervention at this stage even to the extent of amputation. This lytic reaction is a normal sequel of irradiation and is followed by gradual recalcification. It is important to protect the bone against stress and trauma during the lytic phase so as to avoid fracture. Recalcification in the tumor area requires many months and may never completely fill in the volume originally occupied by the lesion. A residual bulky mass may remain permanently. However, in a growing bone essentially all roentgenographic evidence of the tumor (the cystic spaces and the expanded shaft) may disappear after a few years.

OSTEOGENIC SARCOMA. Among the most malignant tumors found in the body are the osteogenic sarcomas. Included in this group are the malignant bone tumors of cartilaginous origin known as chondrosarcomas. The histologic picture of

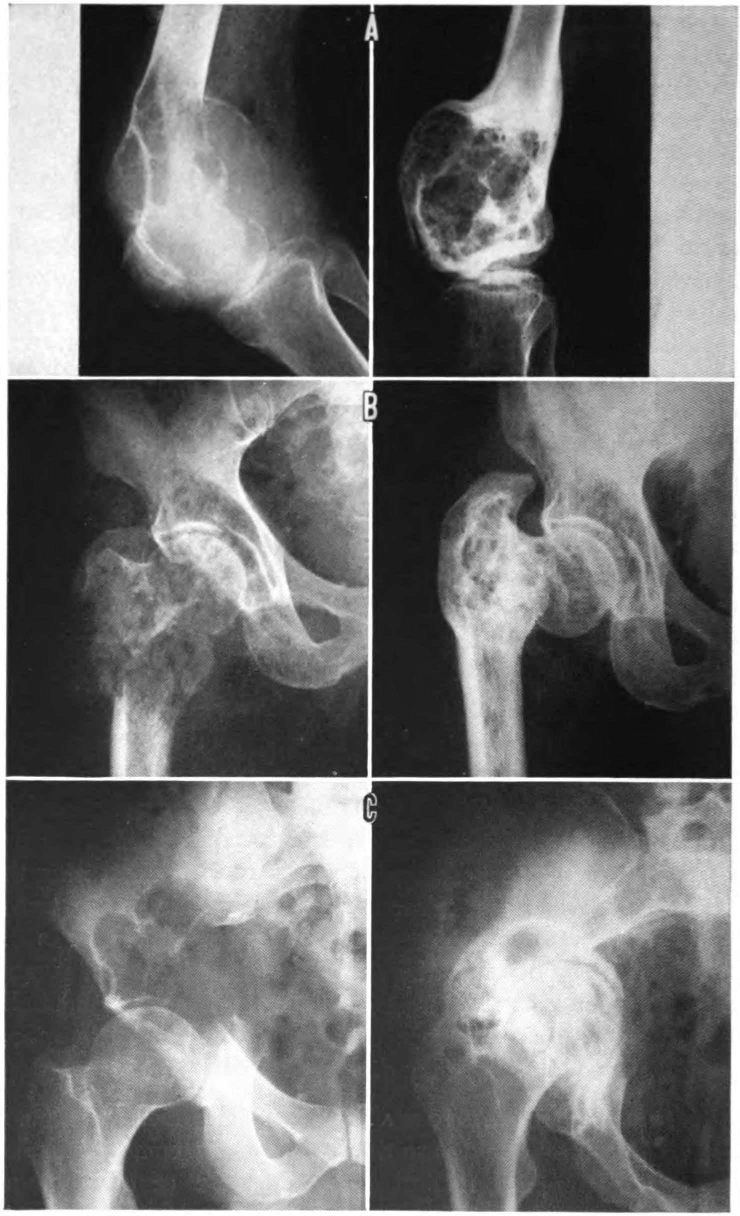


PLATE 104

many of these lesions is complex and confusing and much remains to be learned about them. These lesions occur at any age but are most common in young people. Death usually occurs as the result of pulmonary metastases which appear early in the course.

The treatment of these neoplasms is surgical removal but the results are not brilliant. The primary tumor may be completely and successfully removed but in most patients pulmonary metastases will appear and cause death. Amputation is the usual procedure when the tumor develops in a long bone. These neoplasms respond poorly to irradiation even when large doses are given; despite this, heavy radiation treatment as a preliminary to the surgical procedure has been used by various workers in an attempt to improve the results. Some reports suggest that the combined procedure is of value, others do not. For a number of reasons it is difficult to make an accurate evaluation. The number of cases is always small, the technics of treatment have varied considerably, the tumors are in various stages of development when treated, and sometimes these neoplasms are confused with sarcomas of bone, such as the fibrosarcoma, which have a much better prognosis.

Radiation treatment is usually tried if pulmonary metastases are present when the patient is first seen or if the location of the primary tumor precludes removal. External irradiation is used almost exclusively. Sometimes pain is relieved and the size of the tumor reduced; rarely does complete clinical regression take place although such instances have been reported. The radiation treatment of the pulmonary metastases is nearly always valueless.

←PLATE 104.—*A: left,* giant cell tumor with fracture; recurrence after surgery; *right,* two years after external irradiation, repair of fracture and marked reossification. *B: left,* primary malignant tumor of upper part of femur with fractures in neoplastic area. Histologically, neoplasm was a pleomorphic sarcoma which could not be classified further. *Right,* essentially complete repair 2⅓ years after irradiation; deformity due to inability to maintain fracture fragments in good alignment during repair. *C: left,* plasma cell myeloma of right ilium. Shortly after, the femur perforated the lytic region. *Right,* nine years later, repair after radiation treatment. This case is unusual in that the iliac lesion is the only one present.

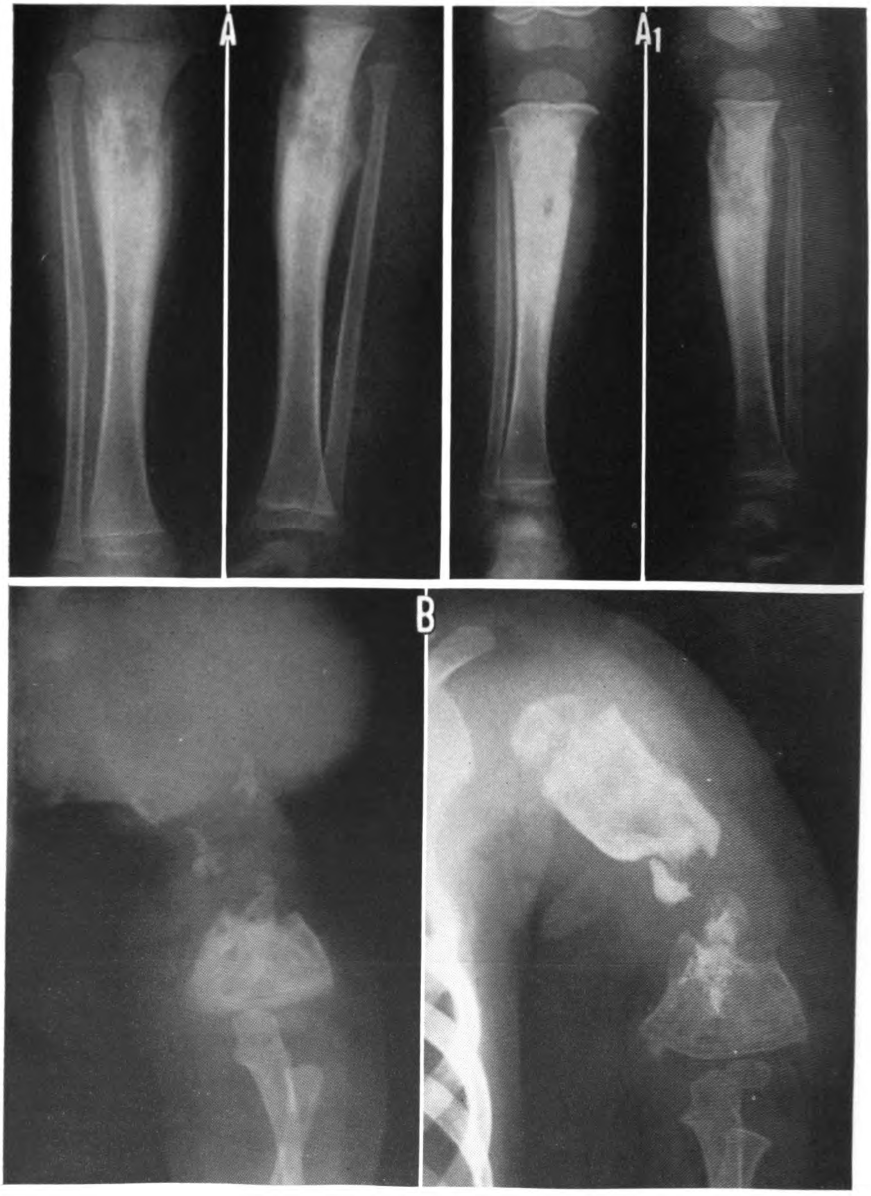


PLATE 105

EWING'S TUMOR. In 1921, Ewing segregated a clinical and pathologic entity from the group of malignant tumors in bone to which he gave the name endothelial myeloma. This neoplasm, now generally known as Ewing's tumor, is found most often in persons less than 25 years of age. It is a highly malignant neoplasm which metastasizes to the lungs as does the osteogenic sarcoma; more often, however, secondary deposits appear in other bones before pulmonary lesions develop. The roentgenographic appearance frequently is characteristic but many times closely resembles that of acute osteomyelitis. The clinical course may also simulate osteomyelitis. The supposedly characteristic roentgenographic signs of osteogenic sarcoma are sometimes seen in Ewing's tumor, making differential diagnosis difficult. Further difficulties arise from the fact that a metastasis in bone from neuroblastoma of the adrenal gland may be identical in appearance with Ewing's tumor and even histologic differentiation may be difficult.

A constant feature of this tumor which differentiates it from osteogenic sarcoma is its high degree of responsiveness to irradiation. In this respect it approaches the lymphoblastomas. Regression takes place rapidly and complete repair of the involved bone is a common experience; pain may be relieved within a few days after treatment is begun. The dramatic improvement after irradiation should not lead, however, to optimism regarding the final result. The prognosis with either surgical or radiation treatment or both is grave. Only too often removal of the primary tumor by surgery or successful eradication by irradiation is followed by the appearance of visceral or osseous metastases. Vigorous irradiation of the primary site that completely destroys the lesion can be followed by years of freedom from the dis-

---

←PLATE 105.—Ewing's tumor. *A*, characteristic appearance of Ewing's tumor of tibia in frontal and lateral projections. A_1, considerable repair of osseous changes 2½ months after vigorous irradiation. Amputation was done shortly after; no tumor tissue was found on microscopic examination. Several months later pulmonary metastases appeared. *B: left,* recurrent Ewing's tumor of left humerus with extensive bone destruction and large soft tissue mass; *right,* following irradiation for palliation, the mass disappeared and considerable reossification took place.

PLATE 106

ease before secondary lesions appear. A five year interval without recurrence or metastasis is no guarantee of cure since cases are reported in which these have appeared as late as 11 years after treatment.

For the metastases of Ewing's tumor irradiation is the only form of treatment and its value as a palliative measure is great. Pain can be alleviated, abdominal and pulmonary masses can be reduced in size or even made to disappear completely and defects in bone can be repaired. But dissemination of the neoplasm continues regardless of treatment and death follows.

MYELOMA. Myeloma arises in bone but from the cells of the bone marrow and not from cells concerned with the production of osseous tissue. The type of cell constituting the neoplasm varies, but the plasma cell type is the most common. The disease is usually generalized but sometimes a single focus is present for months or years before other lesions are seen. It is generally believed that this tumor is of multicentric origin. The destructive areas in the skeleton give rise to pain and with diffuse involvement of the bone marrow anemia appears. Radiation treatment may alleviate pain since this neoplasm is relatively sensitive to radiation effect, and there is suggestive evidence that life is prolonged by this type of treatment. Occasionally a solitary lesion is the only manifestation and can be eradicated by irradiation.

PRIMARY RETICULUM CELL SARCOMA OF BONE. In 1939, another primary malignant bone tumor was segregated from the general group of bone tumors. Primary reticulum cell sarcoma of bone is a malignant tumor histologically identical with reticulum cell sarcoma elsewhere in the body. It arises from the reticuloendothelial structures of bone, in a single focus in bone, and has the capacity for regional and remote metastasis.

←PLATE 106.—*A: left,* metastatic neoplasm in left ilium from unknown primary tumor; *right,* reossification after irradiation. *B: left,* destruction of lower half of sacrum by adenocarcinoma originating in uterine corpus; *right,* considerable reossification after irradiation. *C: left,* Schüller-Christian disease; destructive lesion in left ilium; *right,* complete repair of defect followed irradiation.

It is usually found in the second to fourth decades of life. Characteristically it is associated with striking absence of general debility. The tumor is remarkably radiosensitive and exhibits a high degree of radiocurability in patients who do not have clinically evident distant metastasis. X-ray treatment is the method of choice, and survival rates (at five years without evidence of disease) as high as 48 per cent have been reported. However, metastasis or recurrence may develop 10 or more years after treatment; frequently these may be controlled by further treatment.

SCHÜLLER-CHRISTIAN DISEASE. Destructive osseous lesions develop in the disorders of lipid metabolism classed as histiocytosis or xanthomatosis. Schüller-Christian disease is the most frequent offender and may produce destructive lesions of startling proportions, especially in the skull. Although not a neoplasm, repair follows moderate doses of radiation. Since repair is a rather constant sequel to irradiation, it is believed that the role of radiation is significant. However, spontaneous repair does occur and, furthermore, in several cases we have seen the interesting phenomenon of lesions which were not irradiated healing concurrently with the irradiated sites. Closely related to Schüller-Christian disease is EOSINOPHILIC GRANULOMA of bone. It may appear as single or multiple destructive lesions which may be adequately treated by surgery or irradiation but often shows a remarkable tendency to spontaneous healing.

THE CHEST

BRONCHIAL CARCINOMA. Of the malignant neoplasms arising in the chest, the most important is the bronchial carcinoma. The number of cases of this disease has been increasing, in large part owing to increased knowledge of the characteristics of this neoplasm which has resulted in more accurate diagnosis. There is evidence, however, suggesting that an actual increase in incidence has taken place. Because of this much attention has been devoted to study of the clinical manifestations and gross and microscopic pathologic features of this con-

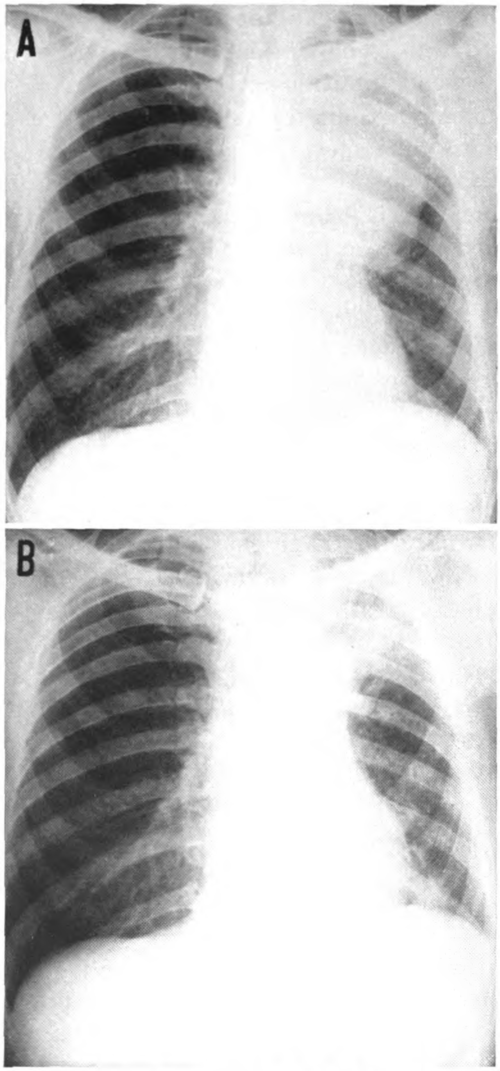


PLATE 107.—*A*, bronchial carcinoma with atelectasis of left upper lobe, inoperable because of mediastinal metastases found during exploratory thoracotomy. *B*, resolution of atelectasis after vigorous irradiation; evidence of radiation fibrosis in deviation of mediastinal structures to left side.

dition. The roentgenographic appearance, which is diverse, has been analyzed and such specialized diagnostic measures as bronchography and bronchoscopy have been developed—the latter in particular permits the establishment of a positive histologic diagnosis by removal of a specimen from a visualized bronchial lesion.

Therapeutically this neoplasm presents a challenge to modern medicine which has been met only in a small way. The brilliant technical advances of thoracic surgery have achieved the goal of total removal of a lung, and cures have been obtained by this radical operation. Yet the ability of the thoracic surgeon to cure large numbers of patients of this disease is thwarted because in most cases the tumor has extended beyond the limits of operability. It has been estimated that of all patients seen with this disease, the current five year survival rate is somewhere between 5 and 10 per cent. The extreme importance of bending every effort to make the diagnosis before the tumor has passed beyond the operable stage is self-evident, but it must be realized that often such efforts will be futile; because of aggressive malignancy, the tumor will be beyond the scope of operation by the time it can be detected. Radiation treatment as practiced today does not have sufficient promise of cure to compete with surgery in the treatment of patients in whom pneumonectomy is possible. In cases of known bronchial carcinoma in which the operation seems possible on the basis of extent of the lesion and general condition of the patient, a trial of irradiation cannot be considered justifiable, because it may involve a delay of weeks or even months and during this time the lesion may extend beyond the operable stage.

The bronchial carcinoma is not completely unaffected by irradiation. Indeed the literature contains reports of a small number of five year cures in histologically verified lesions treated by external irradiation. Vigorous treatment will usually produce some degree of regression, and patients are sometimes seen in whom total clinical regression takes place but this is rarely permanent. Palliation and prolongation of life have followed such treatment. The usual technic is high-voltage external irradiation carried out fractionally, with the x-ray beam directed through

multiple fields. Doses of the order of 3,000 r as measured in air are given to each of the three, four or more fields that may be used. The location of the lesion and its size are estimated from roentgenographic and bronchoscopic data, but its size in particular may be hard to judge because part of the abnormal shadow seen on the roentgenogram may be caused by regional pneumonitis or atelectasis. Such heavy irradiation will produce damage of lung parenchyma in the form of radiation fibrosis in the regions of high dosage but this is no more, and usually considerably less, disadvantageous than total removal of a lung. Work is being done with x-rays generated at 1 Mev or more, but there is reason to doubt that striking results will be obtained.

In addition to external irradiation, intrabronchial applications of radium have been used. This difficult technical procedure has certain inherent disadvantages largely related to the rapid decrease in radiation intensity with increasing distance from the applicator. Some patients obtain temporary alleviation of chest symptoms from less intensive external treatment than has been described, and attempts to obtain such palliation are usually warranted. When extrathoracic metastases are present, such as in supraclavicular lymph nodes, brain or skeleton, a full-scale radiation attack on the primary site is not advisable. The symptoms of skeletal metastases may frequently be relieved but the results are not as good as in carcinoma of the breast.

BRONCHIAL ADENOMA. Interesting but much less common bronchial lesions are the bronchial adenomas. These lesions probably are not true adenomas and pursue a much more benign course than the bronchial carcinoma. They recur locally if not completely removed or destroyed. Some evidently are low-grade carcinomas and after a course protracted over some years will metastasize. Among various hypotheses about their nature that have been advanced, one of the most interesting is that they belong to the general group of salivary or mucous gland neoplasms. Certain members of this group are moderately responsive to radiation. Reports of disappearance of this lesion after radiation treatment have appeared in the literature and we have had one or two similar experiences. Besides total pneu-

monectomy, simple local removal with bronchoscopic forceps and local electrocoagulation have been used.

OTHER INTRATHORACIC NEOPLASMS. Many types of intrathoracic neoplasms other than bronchial carcinomas are encountered, but the incidence is relatively low. Benign tumors such as neurofibromas, dermoid cysts and others are seen. Malignant tumors of sarcomatous nature also occur. With rare exceptions irradiation has nothing significant to offer in these and cure must depend on total surgical removal. However, the most common malignant involvement of the mediastinum is that seen in the lymphoblastomatous diseases and these, of course, are treated by radiation methods.

PULMONARY METASTASIS. Pulmonary metastases from extrathoracic primary tumors occur with great frequency. With rare exceptions irradiation is the only available method of attack. It is readily understood that the results of such treatment are very poor since these lesions are a manifestation of the generalization of the primary tumor. All that can be hoped for is some measure of palliation; exceedingly rare instances of apparent cure have been reported. Irradiation of pulmonary metastases from such neoplasms as melanoblastomas and osteogenic sarcomas, among others, is probably never of value; in carcinoma of the breast an occasional patient will obtain significant palliation but most will not. Remarkable temporary regressions have occurred in patients with Ewing's tumor, some of the testicular carcinomas and some neoplasms not characterized by a high degree of radiosensitivity. Patients in the metastatic stage of the disease present the problem of whether or not radiation treatment of the lungs is warranted. Decision will be based on a variety of factors: the type of neoplasm, the condition of the patient, the extent of metastatic involvement elsewhere in the body, the condition of the primary tumor, the probable expectancy of life and so on.

THE GASTROINTESTINAL TRACT

Nearly half of all cancer deaths are caused by the malignant neoplasms of the gastrointestinal tract. The results of the cur-

rent methods of treatment of these tumors are poor; in some types cure is virtually impossible, but in others it has been obtained. Surgery constitutes the primary method of attack; radiation therapy plays a minor role.

CARCINOMA OF THE ESOPHAGUS. Few cases of carcinoma of the esophagus have ever been treated successfully. Great difficulties stand in the way of cure by radiation therapy. Of squamous cell character histologically, the carcinoma of the esophagus is probably no more radioresistant than carcinoma of the cervix uteri. Although the results in the latter are fair, successful eradication of the esophageal lesion has been achieved only in isolated cases, if at all. The esophagus is a thin-walled organ which cannot withstand the severe radiation reaction tolerated by the uterus. A disposition of radium sources to obtain adequate irradiation of all parts of the neoplasm is possible in the cervix but not in the esophagus. The esophageal lesion is deep-seated and the introduction of very large doses into the tumor by external irradiation offers considerable difficulty.

Intracavitary and interstitial radium treatment as well as external x-ray irradiation have been tried. Many technics for introducing and maintaining radium sources in the lumen of the esophagus at the level of the lesion have been used but satisfactory results have not been obtained. The fundamental difficulty is that the luminal surface of the tumor gets a high dose but the infiltrating advancing margin, being farthest from the radium, receives a much smaller dose. Furthermore, the radium dose of necessity must be concentrated in a relatively short period of time which minimizes the selective action of the radiation. High-dosage radium treatment not infrequently is followed by perforation, which is nearly always fatal. Interstitial irradiation is difficult and also dangerous.

Most workers agree that external irradiation is the technic of choice in the attack on this neoplasm. Multiple fields, as many as six or eight, laid out on the chest wall are used. One or more are treated daily with high-voltage radiation until large doses have been delivered to each field; six weeks of daily irradiation may be necessary. It should be realized that such a procedure

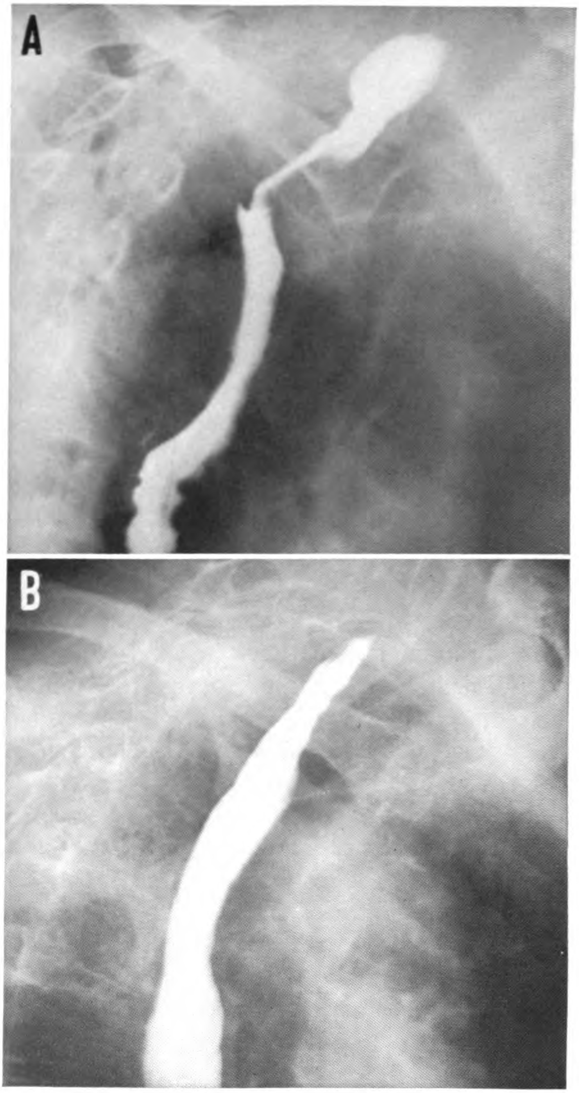


PLATE 108.—*A,* carcinoma of esophagus, a short annular defect at and just below level of clavicle. Below the tumor the esophagus curves around the aorta. *B,* essentially normal lumen after intensive external irradiation.

is a major undertaking and may tax the patient's tolerance, particularly if his general condition is poor, which is frequently the case in esophageal carcinomas.

The results of external irradiation have been poor although palliation following partial tumor regression is not uncommon. The ability to swallow may increase considerably, even temporarily return to normal. Even for such palliation high doses are required. With the use of higher doses and, more particularly, high-energy radiation from supervoltage x-ray machines or cobalt-60 sources, frequently using rotational technics of irradiation, more instances are being reported of complete clinical regression with re-establishment of a normal esophageal lumen; and a small number of patients have gone for several years without evidence of recurrence. With the use of high-energy radiation, the treatment has been found to be more simple technically, for the radiotherapist and, furthermore, is better tolerated by the patient.

The most remarkable results obtained with radiation treatment are embodied in a recent report.[1] Of 29 patients seen, three were alive and normal in every respect 10–12 years after irradiation with a 1 Mev x-ray beam, a cure rate of 10.3 per cent. Ten of the 29 were not treated (poor condition), and in four treatment had to be discontinued before completed because of rapidly declining general condition. Three survivors of the 14 completely treated (corresponding to a group in whom surgical resection would have been done) gives a survival rate of 21 per cent.

Advances in the technic of surgical attack on esophageal carcinomas have been made to the point that today it is possible to remove the esophagus and create an artificial passage. As is always the case, complete excision means cure, but only small lesions can be completely excised. Although every effort should be made to diagnose this disease while the tumor is small, the obstacles in the way of attaining this goal loom large. It is questionable that there will be many candidates for such operative procedures. It is hoped that, with additional experience,

(1) Buschke, F., and Cantril, S. T.: Results of supervoltage roentgenotherapy of esophageal carcinoma, J. Thoracic Surg. 26:105-108, July, 1953.

supervoltage irradiation will offer significantly better curative and palliative results than have been obtained surgically.

CARCINOMA OF THE STOMACH, SMALL INTESTINE AND COLON. In the treatment of carcinoma of the stomach, the small intestine and the colon, surgery dominates the field. At times irradiation is effective against rectal carcinomas for palliation but not against those of the remainder of the colon, small bowel or stomach. It should be remembered that some neoplasms of these organs simulate the carcinomas and respond well to radiation treatment. These tumors are the lymphoblastomas, usually occurring as lymphosarcoma, and are relatively rare.

Carcinomas of the liver, gallbladder and pancreas are not candidates for radiation treatment.

Carcinoma of the anus, an uncommon lesion, arises from the stratified squamous epithelium lining this short canal. Histologically most tumors of the anus are squamous cell carcinomas of various degrees of differentiation. Radiation therapy, usually in the form of interstitial or surface radium applications, has been used with variable results. The disadvantage of this form of therapy is the inability to treat metastatic nodal involvement. In tumors restricted to the external aspect of the anus without involvement of the rectal mucosa, radiotherapy may be considered indicated; these usually are well differentiated and unlikely to lead to lymph node metastases. For the more advanced lesions, abdominoperineal resection of the rectum and anus gives the best outlook for cure.

INTRACRANIAL AND SPINAL CORD TUMORS

Of the considerable variety of neoplastic conditions found within the cranial cavity, radiation therapy is intimately concerned with the medulloblastoma and the pituitary adenomas. In the former, irradiation may be considered the basic treatment; the essential function of surgery is to exclude other types of neoplasms which lend themselves to removal. In the latter, under many clinical circumstances irradiation is the indicated form

of therapy. In other intracranial tumors, irradiation is used postoperatively or for recurrences, but the results are very poor. An occasional glioblastoma will show clinical response with prolongation of life. Although other tumors may infrequently do the same, radiation treatment is essentially valueless in meningiomas, acoustic neuromas, craniopharyngiomas, dermoids and chordomas.

MEDULLOBLASTOMA. The medulloblastoma is a highly malignant tumor which only exceptionally arises elsewhere than in the cerebellum. Usually it occurs in children and the clinical picture is that of increased intracranial pressure resulting from obstructive hydrocephalus. Characteristically this malignant neoplasm not only infiltrates locally but also metastasizes by way of the cerebrospinal fluid. Metastatic implants are found in the ventricles and the subarachnoid spaces around the spinal cord. A second feature of this tumor is that it exhibits a relatively high degree of radiosensitivity.

Since other tumors occur which are amenable to surgery, it is usually considered advisable to operate in all cases in which the diagnosis of a posterior fossa lesion is made. A preoperative diagnosis of the specific type of neoplasm is not possible. A second reason for immediate operation is the necessity for relieving the increased intracranial pressure, which can be done by subtotal resection of the neoplasm.

The radiation treatment of medulloblastoma is incomplete unless the entire cerebrospinal axis is irradiated. The technic is arranged so as to irradiate the posterior cranial fossa and the entire ventricular system as well as the entire spinal axis. Cure of medulloblastoma is uncommon; it appears that it has never been cured by surgery. The addition of irradiation has prolonged life beyond that obtainable by surgery alone. In general the literature deals with prolongation of life rather than cure, but isolated cures are reported. Of 26 patients treated at the University of Michigan from 1938 to 1946, seven (26.9 per cent) were alive six to 11 years after surgery plus irradiation. The results are, however, less favorable than suggested by the survival rate since one of the seven is a helpless invalid; two others

have been having convulsions for two and three years. Four patients are well, one having had an attack of hemiplegia with recovery 7½ years after treatment.

PITUITARY ADENOMA. Both the chromophobe and the eosinophile adenomas of the pituitary gland produce constitutional as well as local symptoms. In the chromophobe lesion the constitutional symptoms are those of hypopituitarism and are due to damage of the gland by the enlarging tumor; such symptoms are not always present. The eosinophile lesion produces the clinical picture of acromegaly—before skeletal growth has ceased, gigantism results—and does so because of abnormal pituitary secretion by the cells of the adenoma. The local symptoms are the same in both types of adenoma and are caused by pressure on adjacent structures by the tumor. Pressure on the optic chiasm causes visual field defects, usually but not always bitemporal, and decrease in visual acuity; when the adenoma is small such changes may be absent. Headache is common and often severe.

Both surgery and irradiation have been used in the treatment of the pituitary adenomas. With increasing experience the indications for each are gradually being clarified and defined. The chief value of surgery lies in the fact that, by partial removal of the tumor, pressure on adjacent structures can rapidly be relieved. The operation is a major procedure which carries a mortality risk, although the brilliant advances in neurosurgical technic and the recent introduction of endocrine replacement therapy have reduced this to a reasonable level. The eosinophile adenoma responds favorably to radiation treatment more frequently than the chromophobe type, and it is generally agreed that irradiation is indicated unless vision is so reduced that immediate decompression appears imperative. In the chromophobe adenoma some workers prefer immediate operation followed by irradiation in all cases, whereas others operate only after radiation treatment has been tried and found ineffective. The chromophobe adenomas frequently degenerate to form cystic lesions—acellular tumors that do not respond to radiation. When vision is slightly or not at all affected, it seems wiser

to make a thorough trial of radiation therapy before undertaking the surgical procedure.

External radiation treatment through two or more fields cross-firing the pituitary gland is the technic employed. Some type of fractional administration is used; we treat daily through two lateral fields usually to a dose of about 4,000 r in the pituitary tumor, using high-energy radiation. In some cases of either type of adenoma such treatment may be of no benefit and progession of the visual changes will necessitate operation. In others, visual defects may not improve but will remain stationary; in these the tumor may have decreased in size but nerve damage is so great that recovery is impossible. Many patients show improvement in vision varying from complete restoration to normal to partial restoration with residual defects which depend on the amount of regression of the adenoma and on the extent of permanent nerve damage. If the pituitary gland can recover from the damage produced by the pressure of the chromophobe adenoma, constitutional symptoms will be partially or completely relieved. The characteristic systemic changes seen in acromegaly rarely are reversible, although there are exceptions. Recently we observed a patient with acromegaly of eight months' duration in whom all the typical features of the disease were well developed. Two months after radiation treatment not only had marked improvement taken place in the visual defects, but the advanced acromegalic facial appearance had receded almost to normal, the thickened tongue had decreased in size so that speech was again articulate and the enlarged hands and feet were reduced in size. In long-standing cases of acromegaly the pituitary gland may be completely destroyed, and, if the adenoma degenerates to form a cystic lesion, no pituitary function remains and hypopituitarism develops.

SPINAL CORD TUMORS. In practically all of the tumors that arise in the spinal cord or from its membranes successful eradication depends on complete surgical excision. Many of these lesions are irradiated postoperatively; there is suggestive but not positive evidence that in some tumor types this produces better results than surgery alone. Other neoplasms which are

not spinal cord tumors are found in the neural canal. Hodgkin's disease and other types of lymphoblastoma are occasionally encountered; if pressure on the cord has not been of sufficient degree of duration to produce permanent nerve damage, irradiation will be followed by regression of the neurologic abnormalities. It is advisable to give fairly large doses in an attempt to discourage recurrence. Remote primary neoplasms may metastasize to vertebral bodies, from which the neural canal may be invaded, or directly to the canal; irradiation relieves neurologic symptoms in some of these cases. A rare primary tumor involving a vertebral body and the neural canal at the same level with resultant pressure on the cord is the cavernous hemangioma. Although this lesion has generally been treated by decompressive laminectomy followed by irradiation, irradiation alone in adequate dosage produces rapid relief of cord compression and restores normal function and thus the hazards of severe hemorrhage always encountered at operation can be avoided. Syringomyelia has been treated by external irradiation with reported good results; our own cases have done poorly with this form of treatment.

16

Infections and Miscellaneous Conditions

X-RAYS AND THE radiations of radium have been used in the treatment of a variety of diseases which have no relation to malignant neoplasia. Excellent therapeutic results have been reported in an amazing collection of diverse conditions. Only too often these could not be duplicated by other workers or were found to be due to the coincidence of irradiation with either a healing phase of the disease or a temporary spontaneous remission. Excluding these, there remains a considerable number of conditions in which irradiation may be profitably used, and many, though not all, will be discussed in this section.

INFECTIONS

There is no doubt that small amounts of radiation favorably influence the healing of certain infections. Furuncles, carbuncles, early stages of other types of abscesses and tissues involved by cellulitis or lymphangitis frequently respond remarkably well. In the early stages of the process the infection may resolve without suppuration; when irradiated later in the course, suppuration may be accelerated, permitting earlier incision and drainage. Although the results are much better in acute inflammations, occasionally a subacute or chronic process responds in a similar fashion. How small amounts of radiation produce such results

is not clear. The observation has been made that the polymorphonuclear leukocytes increase in number in the irradiated area. Certainly lymphocytes in the region will be affected—it has been postulated that their destruction with release of intracellular contents is responsible for the favorable effect—but the role of the lymphocyte in combating acute infections is believed to be minor. Possibly the answer will be found in an altered local immunologic phenomenon.

In acute infections in the region of the orbits (on the forehead, cheeks and nose) where extension of the process always carries the threat of cavernous sinus thrombosis, the value of small doses of radiation should not be overlooked. Treatment is usually restricted to irradiation and local application of heat until drainage takes place spontaneously. Erysipelas has frequently been successfully treated by irradiation, but with the advent of the newer methods of chemotherapy this has become less important.

In acute parotitis, which is most commonly seen postoperatively, the results of irradiation are good in a large proportion of cases, and incision and drainage with the possible annoying sequel of a parotid fistula are rarely necessary. Likewise in postpartum acute mastitis the incidence of abscess formation in the breast can be markedly reduced by such treatment. In both of these conditions the earlier treatment is given, the better the results; in our institution such conditions are considered emergencies and are treated as soon as detected. Formerly acute postoperative parotitis was considered a dangerous complication; today, owing in part to improved methods of postoperative care, this is not the case, but the role of irradiation is important. Among the most dramatic responses seen in radiation therapy is the change that often takes place after irradiation of acute mastitis in a lactating breast. The patient may have swollen, indurated, erythematous, very tender breasts and, with chills and fever, appear acutely ill. Within 24 hours after a dose of 100 r is given to each breast (we usually use high-voltage radiation), the patient feels almost normal, fever is low and the breasts are much improved. After a second dose the breasts may become entirely normal; rarely are more than three doses on consecutive

days necessary. The technic of treatment in the other infections mentioned is similar, but usually less penetrating radiation is employed.

Irradiation plays a part in the treatment of tuberculosis but its role is narrowly restricted. No form of pulmonary tuberculosis is amenable to radiation therapy, but in tuberculous lymphadenitis of the peripheral node-bearing areas irradiation produces good results in a fairly large proportion of patients. The most common location for tuberculous nodes is the cervico-supraclavicular region. In contrast with the speedy changes noted in acute infections, regression and involution take place slowly over a period of months after irradiation. The technic of radiation administration differs considerably among workers but commonly the treatment is prolonged for weeks or months by irradiating from once or twice a week to once or twice a month, the doses at each sitting varying approximately from 150 to 400 r with an intermediate voltage such as 130 up to 200 kv. In our hands the best results have been obtained by a short course of daily fractional irradiation to a total dose of about 1,000 r as measured in air, using 200 kv. The effect of such treatment is observed for about three months, and if regression is not satisfactory the course is repeated. In dermatologic practice some forms of tuberculosis of the skin are found to respond well to irradiation. Many other forms of tuberculosis have been treated by x-rays or radium but with dubious results. It is generally agreed that tuberculous lymphadenitis of mediastinal and hilar nodes should not be irradiated except in rare instances. X-ray treatment has been used in tuberculous tracheobronchitis and the opinion is frequently expressed, although the evidence is not too good, that it may be of some value in the hyperplastic form.

In actinomycosis radiation therapy is of proved value in the cervicofacial form but has been little used since the advent of the antibiotics. Adequate irradiation, which in this disease means vigorous irradiation, can be depended on to cure a rather high percentage of patients. Daily fractional treatment with high-voltage radiation is probably the best method but the procedure must be continued until a dose of 2,000–3,000 r is attained, a dose relatively high for a noncancerous condition.

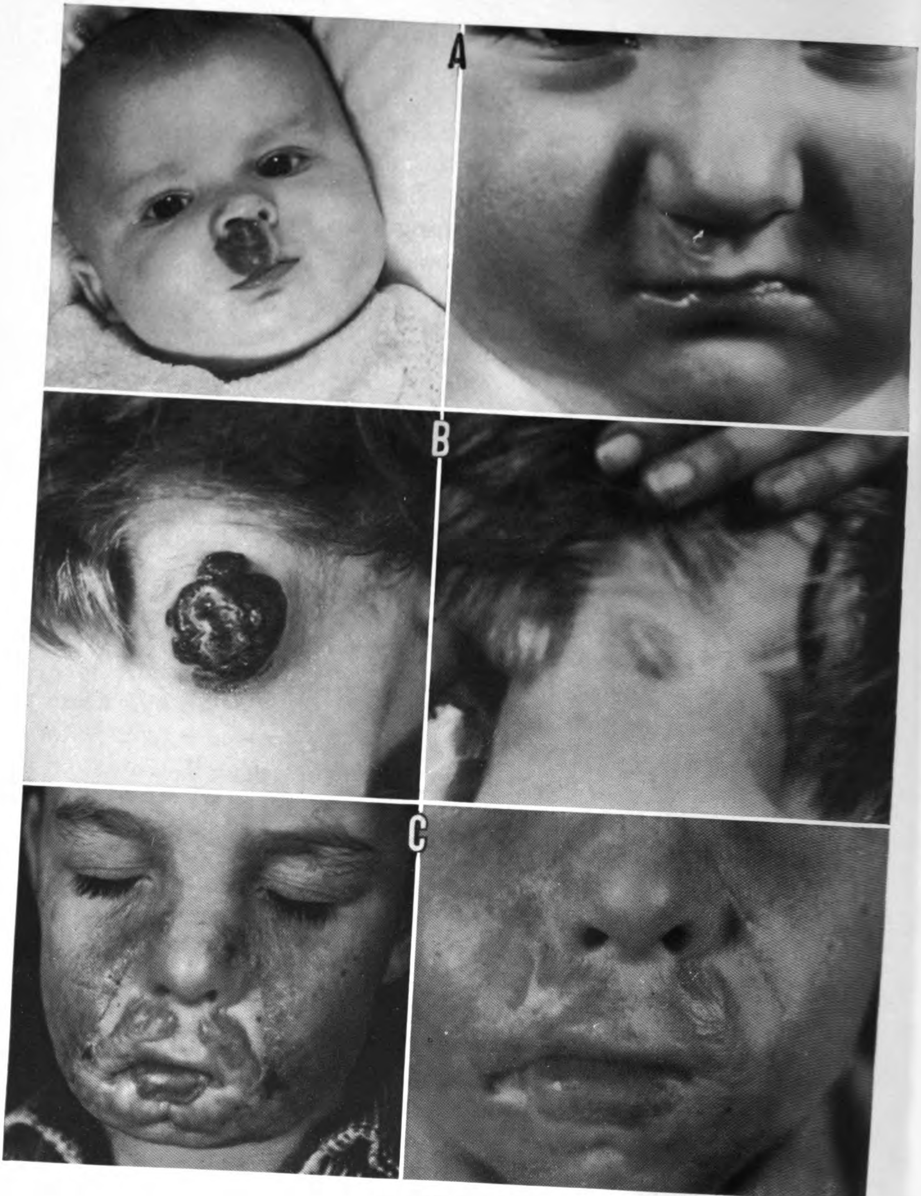


PLATE 109

In the intrathoracic forms of this disease radiation treatment has been unsuccessful. A few patients with abdominal and pelvic actinomycoses have been cured; as in the cervicofacial form, relatively high doses are necessary to obtain a good result. Involution takes place slowly, requiring several months. Blastomycosis is another mycotic infection in which good responses to irradiation are frequently seen. The best results are obtained in cutaneous involvement, the response of visceral and osseous lesions is much less favorable.

MISCELLANEOUS CONDITIONS

HEMANGIOMA. Radiation methods occupy a prominent position in the treatment of certain hemangiomas. It must be remembered that there are diverse kinds of hemangiomas with varying pathologic features. The port-wine stain (nevus flammeus) is a simple capillary angioma which does not project above the general skin surface or ever form a subcutaneous tumor although the underlying tissues not infrequently are somewhat hypertrophied. This lesion, even early in life, does not respond satisfactorily to x-ray or radium and such treatment is contraindicated.

The common lesions of infancy are the strawberry mark which forms a projecting red growth composed of multiple small vessels and the cavernous hemangioma. The latter may involve the skin or subcutaneous tissues or both. In an infant the typical history shows that at birth either no lesion or a very small one is present. Within two or three weeks a lesion appears and enlarges fairly rapidly, or the tiny lesion grows, sometimes with startling rapidity. These are the lesions which respond well to

---

←PLATE 109.—*A: left,* cavernous hemangioma of upper lip; *right,* one year later, after external x-ray irradiation. *B: left,* large cavernous hemangioma on back of neck; *right,* 19 months later, after x-ray treatment. *C: left,* multiple circumoral keloids following burn; mouth orifice severely reduced. *Right,* one year later, after several x-ray treatments, keloids have flattened, their color is reduced and ability to open mouth has increased markedly.

irradiation. Radium was usually used in the past but in recent years x-ray treatment has been used with increasing frequency. For lesions that are only 1 or 2 mm. thick, beta irradiation is satisfactory; by using a lightly filtered radium source a high proportion of the beta rays of radium pass through the filter and produce ionization in the first few millimeters of tissue adjacent to the source. For bulkier and subcutaneous masses either gamma or x-ray radiation must be used to get an adequate distribution of ionization throughout the lesion. Small doses are used. Treatment must never be carried to the point of skin damage. In these instances it is better to err on the side of under- rather than overdosage. This is particularly important because there is evidence that spontaneous regression is the rule rather than the exception. The natural history of these lesions has been described as consisting of increase in size during early life until the last part of the first year, after which involution, usually starting at 2 years of age, slowly takes place during the next four to five years.

In our own practice, one or two small doses are used when the lesion is in the growing phase; usually this constitutes the entire radiation treatment. The patient is kept under observation until satisfactory involution (largely spontaneous) is apparent. In patients past the growing phase, frequently no radiation or other form of specific treatment is employed. In extensive lesions which can be difficult to manage without producing late skin effects, the best results follow the use of a minimum of radiation plus patient waiting for spontaneous involution. One must keep in mind that concern for the character of the post-irradiation skin is not in terms of five years after treatment but rather 20–40 or even more years.

Cavernous hemangiomas are found in adults in various organs and locations. They are much less responsive to radiation than the lesions occurring in infancy and often unsatisfactory regressions follow even large doses. In some parts of the body collections of blood vessels, usually veins, may form an angiomatous mass. Although frequently termed hemangiomas, they are actually fully formed normal vessels rather than a benign neoplasm and occur on the basis either of congenital derangement

of the local vascular pattern or of some circulatory disturbance. Such masses of vessels react to radiation exactly as other normal vessels. Angiomatous masses may be composed of veins and of arterial vessels as indicated by muscular layers; the latter may be incompletely formed. These angiomas usually enlarge with the passage of time and may appear to extend into regional tissues. Although difficult to demonstrate directly, these lesions contain arteriovenous fistulas and show negligible response to irradiation. Besides the types described there occurs in the skin a lesion which has the appearance of a spider-like capillary telangiectasia; it does not react well to irradiation.

The lymphangiomas, of which there are a number of varieties, are considerably more resistant, even in infancy, than the hemangiomas. A few will decrease in size and even disappear after moderate radiation treatment, and when surgical excision is undesirable radiation therapy may be given a trial. An interesting lesion is the so-called hemolymphangioma which basically appears to be a lymphangioma with blood cells occupying some of the vesicles; often the lesion has a verrucose appearance. In our experience this angioma has responded poorly to irradiation. Radiation treatment is not indicated in nonvascular nevi.

THYMUS. A great deal has been written on the radiologic diagnosis and treatment of the so-called hyperplastic thymus of infancy and childhood. Composed largely of lymphoid tissue, the gland can readily be reduced in size by small amounts of x-rays delivered through the anterior chest wall. A number of uncertainties are associated with the clinical indications for irradiation of the thymus. Apparent enlargement of the upper mediastinal shadow is not uncommon in roentgenograms of infants; many times this is due not to a large thymus but to changes associated with phases of respiration and positioning of the patient. However, when the upper mediastinum is enlarged beyond normal limits and presents a configuration typical of the thymus, the question arises whether the condition is abnormal and irradiation is indicated. In an otherwise normal child it seems doubtful that any real indication for radiation treatment exists. In children about to be subjected to surgery the enlarged gland has been often irradiated preoperatively, al-

legedly because of fear that anesthetic difficulties may develop should further enlargement take place during the operation; there does not appear to be any sound evidence for this fear. Actually the apprehension is probably based on the possibility of sudden death in persons demonstrating the thymicolymphatic constitution of which thymic enlargement is one manifestation. We need not be concerned here over the controversy regarding the occurrence of sudden death under conditions of stress in the thymicolymphatic type; the point that does concern us is that reduction of the size of the thymus by irradiation does not alter the constitutional type and therefore could not prevent the feared eventuality. Thymic enlargement has long been associated with dyspnea in youngsters, presumably on the basis of tracheal compression; this has been considered a clear indication for irradiation. Although one would hesitate to say that the type of enlarged thymus discussed here never causes dyspnea, it has been our experience that in each such case encountered another cause for the dyspnea was found shortly after treatment was given.

In general, it appears that no adequate justification exists for radiation treatment of the normal or the so-called enlarged thymus. Evidence has been presented that such treatment may be associated with an increased incidence of carcinoma of the thyroid gland in children and adolescents. Follow-up studies of our own cases treated a decade or more ago, in process at present, have shown no case of thyroid cancer in about 750 traced patients. The absence of such cases may be related to the small radiation dose and small radiation fields used, the thyroid gland being excluded from the irradiated zone.

ARTHRITIS. Treatment with x-rays is of proved value in the field of arthritis, but its role is restricted. In spondylitis rhizomelique (rheumatoid spondylitis) it can provide not only subjective but also objective improvement. Much has been learned during the past two decades about the clinical manifestations of this disease; consequently, it now can be recognized much earlier. In the characteristic clinical history a vigorous, athletic young man in his late teens or early twenties develops soreness and pain in the lower back and region of the sacroiliac joints.

The rest of the spine, including the cervical portion, becomes similarly involved with progressive stiffness and limitation of mobility. Chest expansion is restricted; coughing and sneezing cause severe pain. Roentgenograms show changes along the margins of the sacroiliac joints which progress to bony fusion across the joint spaces. Progressive calcification takes place in the spinal ligaments and in some patients the entire spine becomes encased in a bony sheath. Ankylosis of the posterior spinal articulations takes place.

In most patients x-ray treatment relieves pain and, in association with this, improves the state of general health. Stiffness of the back from muscle spasm is abolished or considerably reduced, but rigidity due to ligamentous calcification or ankylosis of the posterior articulations is unaffected. Irradiation does not appear capable of reversing established joint, ligamentous and osseous changes. Its effect on the progression of such changes is not definitely known, but some patients do show progressive changes even though the symptoms are largely controlled and they are fairly comfortable. Irradiation is not curative.

Little is known about how radiation produces its effects in this disease, but a reasonable assumption is that it exerts a favorable influence on some underlying inflammatory process. The technic of x-ray treatment consists of relatively small doses through multiple fields over the spine and sacroiliac joints, usually with high-voltage radiation. Doses per field of 250 r at one sitting or 300–400 r in two fractions are usually adequate. Periodic treatment at intervals of one or more months as indicated by the clinical course is practiced.

A note of caution must be added regarding the use of radiation in the treatment of this disease. Experience has shown that the incidence of leukemia in some treated series some years after irradiation is significantly higher than in the general population of similar age distribution. It seems unlikely that there is an association between spondylitis and leukemia. One must weigh the probable benefit of this treatment method against the risks entailed for the individual patient. The risk of developing leukemia is considerably less than the morality noted for interval partial gastrectomy for peptic ulcer in the best surgical hands.

X-ray treatment has been generally unsatisfactory for the peripheral joint involvement of rheumatoid arthritis. Nor does it produce significant relief of symptoms in hypertrophic arthritis, although once in a while some patients obtain transient benefit; other forms of therapy should be exploited before resorting to irradiation. Such conditions as periarthritis, supraspinatus tendon calcification associated with shoulder pain, some forms of bursitis and fibrositis respond with symptomatic improvement often enough to warrant a trial of irradiation.

KELOID. The peculiar hypertrophic form of vascularized scar which develops in some individuals after the healing of accidental wounds, surgical incisions or burns can be favorably influenced by radiation treatment. The pink color of the lesion slowly fades and its bulk diminishes, often to the general skin level. Usually treatment is for the purpose of cosmetic improvement, although at times limitations of function due to such scars require reduction of their bulk. Also the paresthesias that sometimes occur in keloid can be relieved. Treatment is usually given with a superficial type of x-ray beam; small doses may be administered weekly or larger doses at longer intervals. The field of irradiation is restricted to the keloidal tissue. Another approach to the management of these lesions is to excise the keloid and irradiate the wound as soon as union has occurred.

In several other conditions fibrous tissue formations, though not keloids, occasionally are diminished by irradiation with symptomatic improvement or relief. One of these is Peyronie's disease in which fibrous plaques develop about the cavernous bodies of the penis and urethra and produce deformity on erection and frequently pain. In Dupuytren's contracture the fibrous tissue bands or nodules in the palmar aponeurosis may resolve sufficiently to decrease the limitation of finger extension.

CONDUCTION DEAFNESS. Lymphoid hyperplasia in and about the eustachian tube orifice in the nasopharynx produces by obstruction a type of hearing deficiency known as conduction deafness. Satisfactory improvement of auditory acuity follows shrinkage of the lymphoid tissue by small amounts of radiation. A convenient technic is to place a radium source adja-

cent to the tubal orifice in the nasopharynx long enough to deliver the necessary small dose.

OTHER MISCELLANEOUS CONDITIONS. In a number of other miscellaneous conditions irradiation often is helpful. In salivary gland fistulas the secretion of the gland can be temporarily suppressed, during which time the fistula often heals spontaneously. By producing aspermatogenesis the recurrence of spermatocele is discouraged. Occasionally in gastric hyperacidity symptoms which cannot be controlled by the usual methods will be relieved by irradiation of the stomach which produces temporary decrease in gastric secretion. The so-called ganglion of tendons, usually occurring on the dorsum of the hand or wrist, responds to radiation treatment. Irradiation of the ganglions of the involved neural segments in herpes zoster seems to decrease or relieve postherpetic pain in a fair proportion of those treated. In a few patients with myasthenia gravis significant increase in muscular strength follows irradiation of the thymic region, an inconstant effect that has been noted empirically but has no explanation.

Index

NOTES.—Asterisk (*) indicates reference to page of illustrations.
Italicized page numbers indicate treatment.

D

P

U

1. x-rays
2) To correct version of questions
3) To match genetics
4) Skin studies c history
5) Perimetry
6) E.C.G.

14 DAY USE
RETURN TO DESK FROM WHICH BORROWED

This book is due on the last date stamped below, or
on the date to which renewed.
Renewed books are subject to immediate recall.

JAN 23 1967	NOV 3 1975
~~JAN 9 1967~~	JUL 8 1976
MAR 15 1971	
APR 12 1971	
APR 26 1971	
APR 26 1971	
SEP 28 1971	
DEC 27 1971	
~~APR 13 1972~~	
May 13-1972	
1972	
Sept 13, 1972	
JAN 27 1973	

LD 21–50m-8,'57
(C8481s10)476

General Library
University of California
Berkeley